LIGHT AND HEAVY TACTICAL WHEELED VEHICLE FUEL CONSUMPTION EVALUATIONS USING FUEL EFFICIENT GEAR OILS (FEGO)

FINAL REPORT
TFLRF No. 477

by
Adam C. Brandt
Edwin A. Frame

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for
Mr. Allen S. Comfort
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD39) W56HZV-15-C-0030 (WD03)

May 2016

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Approved by:

Gary Bessee

Gary B. Bessee, Director
U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI®)

REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**				
1. REPORT DATE *(DD-MM-YYYY)* 06/30/2016	**2. REPORT TYPE** Final Report			**3. DATES COVERED** *(From - To)* August 2014 – March 2016
4. TITLE AND SUBTITLE LIGHT AND HEAVY TACTICAL WHEELED VEHICLE FUEL CONSUMPTION EVALUATIONS USING FEUL EFFICIENT GEAR OILS (FEGO)				**5a. CONTRACT NUMBER** W56HZV-09-C-0100 W56HZV-15-C-0030
				5b. GRANT NUMBER
				5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Brandt, Adam C.; Frame, Edwin A.				**5d. PROJECT NUMBER** SwRI 08.20638 & 08.21300
				5e. TASK NUMBER WD 39 & WD 03
				5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI®) Southwest Research Institute® P.O. Drawer 28510 San Antonio, TX 78228-0510				**8. PERFORMING ORGANIZATION REPORT NUMBER** TFLRF Final Report No. 477
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army RDECOM U.S. Army TARDEC Force Projection Technologies Warren, MI 48397-5000				**10. SPONSOR/MONITOR'S ACRONYM(S)**
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION / AVAILABILITY STATEMENT UNCLASSIFIED: Dist A Approved for public release; distribution unlimited				
13. SUPPLEMENTARY NOTES				
14. ABSTRACT The U.S. Army Tank Automotive Research and Development Engineering Center (TARDEC) desires to improve the fuel efficiency of the U.S. Army Tactical Wheeled Vehicle (TWV) fleet. This report covers efforts to quantify potential fuel efficiency changes in Light Tactical-Wheeled Vehicles (LTV) and Heavy Tactical-Wheeled Vehicles (HTV) with the use of improved differential/axle lubricants. Candidate lubricants were synthetic based 75W-90 and 75W-140 products, and were compared to a baseline petroleum based 80W-90 gear oil. Fuel consumption improvements were noted for both candidate oils for the LTV, while the HTV showed general trends of improvement for the lower viscosity 75W-90 candidate, and detriment when using the heavier 75W-140 candidate. Stationary axle efficiency testing is recommended to further explore this relationship.				
15. SUBJECT TERMS SAE J2360, fuel efficient gear oil, FEGO, 75W-140, 75W-90, 80W-90, synthetic, gear oil, axle, viscosity, SAE J1321, fuel consumption				
16. SECURITY CLASSIFICATION OF:		**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	143	19b. TELEPHONE NUMBER *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

EXECUTIVE SUMMARY

The U.S. Army Tank Automotive Research and Development Engineering Center (TARDEC) desires to improve the fuel efficiency of the U.S. Army Tactical Wheeled Vehicle (TWV) fleet. This report covers efforts to quantify fuel efficiency changes in Light Tactical-Wheeled Vehicles (LTV) and Heavy Tactical-Wheeled Vehicles (HTV) through the use of improved differential/axle lubricants. This work was conducted in support of TARDEC's Fuel Efficient Gear Oil (FEGO) program.

Full scale vehicle testing was conducted following procedures outlined in the SAE J1321 Fuel Consumption In-Service Test Procedure – Type II. Vehicles utilized for the LTV testing were M1151A1 up-armored High Mobility Multipurpose Wheeled Vehicles (HMMWV). Vehicles utilized for the HTV testing were M1070 Heavy Equipment Transporters (HET). Evaluations were conducted using two unique synthetic based candidate gear oils. The candidate lubricants had viscosities of 75W-90 and 75W-140 respectively, and were compared against a baseline petroleum based J2360 approved 80W-90 gear oil. Testing was conducted on a closed 9-mile paved test track under steady state highway driving, and a stop and go transient driving conditions.

Results demonstrate that the LTV experiences an improvement in fuel consumption with both the tested 75W-90 and 75W-140 candidate lubricants, with largest gains being realized in the more stop and go transient driving cycle. For the HTV, results supported that the heavier viscosity 75W-140 provided a detriment to fuel consumption, while the lighter 75W-90 showed a trend towards improved fuel consumption.

Additional testing on a stationary axle efficiency test stand is recommended to further explore the relationship of driveline mechanical efficiency as a function of both lubricant viscosity and driveline hardware size and loading.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period August 2014 through March 2016 under Contract No. W56HZV-09-C-0100 and W56HZV-15-C-0030. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Eric Sattler (RDTA-SIE-ES-FPT) served as the TARDEC contracting officer's technical representative. Mr. Allen Comfort of TARDEC served as project technical monitor.

The authors would like to acknowledge the contribution of the TFLRF technical and administrative support staff, and the SwRI Fuels and Driveline Lubricants Research Department for their project support and fleet testing expertise.

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ACRONYMS AND ABBREVIATIONS

FEGO – Fuel Efficient Gear Oil

GOCO – Government owned, contractor operated

HET – Heavy Equipment Transporter

HMMWV – High Mobility Multipurpose Wheeled Vehicle

HTV – Heavy tactical vehicle

lbs - Pounds

LTV – Light tactical vehicle

mph – Miles per hour

SAE – Society of Automotive Engineers

sec - Seconds

SwRI – Southwest Research Institute

T/C – Test to control

TARDEC – Tank Automotive Research Development and Engineering Center

TFLRF – TARDEC Fuels and Lubricants Research Facility

TWV – Tactical wheeled vehicle

1.0 BACKGROUND & OBJECTIVE

The U.S. Army Tank Automotive Research and Development Engineering Center (TARDEC) desires to improve the fuel efficiency of the U.S. Army Tactical Wheeled Vehicle (TWV) fleet. Optimization of driveline fluids for improved mechanical efficiency has been identified as a potential source of vehicle fuel efficiency improvement. Previous work has been conducted to measure fuel efficiency changes through the use of updated engine, transmission, and axle lubricants in Medium Tactical-Wheeled Vehicles (MTV) [1,2]. This report covers efforts to quantify potential fuel efficiency changes in Light Tactical-Wheeled Vehicles (LTV), and Heavy Tactical-Wheeled Vehicles (HTV) with the use of improved differential/axle lubricants. All testing was administered by the government-owned, contractor operated (GOCO) TARDEC Fuels and Lubricants Research Facility (TFLRF), located at Southwest Research Institute (SwRI), San Antonio TX.

2.0 APPROACH

The approach for this project was to conduct full scale in-vehicle fuel consumption testing using light and heavy tactical wheeled vehicles in an effort to determine differential/axle lubricant impact on overall fuel consumption. Fuel consumption changes were determined by conducting SAE J1321-like testing on two High Mobility Multipurpose Wheeled Vehicle (HMMWV), and two Heavy Equipment Transporter (HET) to measure differences in response between light and heavy tactical wheeled vehicles. Changes in fuel consumption were compared against a standard baseline differential lubricant.

2.1 TEST METHOD

The test method used for determining vehicle fuel consumption changes was based on procedures outlined in the SAE J1321 Fuel Consumption In-Service Test Procedure – Type II [3]. Some deviations were made from the current approved SAE J1321 method to remain consistent with previous testing [1,2] which had been conducted prior to the method's most recent 2012 revision. These changes are noted in the applicable sections of this report and the attached test reports.

In general, an SAE J1321 test consists of a baseline and test segments, where the mass based fuel consumption of test and control vehicles are compared to establish changes in fuel consumption as a function of some given variable (in this case, differential/axle lubricant). For each run, the total mass based fuel consumed by each vehicle is measured and used to form a Test-to-Control (T/C) ratio. To create a complete segment (baseline or test), a minimum of three T/C ratios must be measured to establish data repeatability. All T/C ratios for a respective baseline or test segment are then averaged to obtain an overall segment T/C Ratio. The segment T/C ratios are used to calculate the changes in fuel consumption as a function the tested variable. A general outline of the data reduction process is shown in Table 1. Consistent with the most recent revision of the SAE J1321 procedure, statistical analysis was conducted on measured data to establish a confidence interval reported with the final result.

Table 1. SAE J1321 Testing Steps

<table>
<tr><td rowspan="6">Baseline Segment: Both Trucks Filled with Same Oil</td><td>Control Truck Fuel Consumed B1</td><td rowspan="2">Baseline Run 1 T/C Ratio</td><td rowspan="6">Baseline Segment Average T/C ratio (all T/C ratios within 2% band)</td><td rowspan="12">Completed SAE J1321 Test for Candidate Fluid - Percent Fuel Saved or Fuel Consumption Improvement Based Upon Change in Segments T/C Ratios</td></tr>
<tr><td>Test Truck Fuel Consumed B1</td></tr>
<tr><td>Control Truck Fuel Consumed B2</td><td rowspan="2">Baseline Run 2 T/C Ratio</td></tr>
<tr><td>Test Truck Fuel Consumed B2</td></tr>
<tr><td>Control Truck Fuel Consumed B3</td><td rowspan="2">Baseline Run 3 T/C Ratio</td></tr>
<tr><td>Test Truck Fuel Consumed B3</td></tr>
<tr><td rowspan="6">Test Segment: Test Truck Filled with Candidate Oil, Control Truck Remains Filled with Baseline Oil</td><td>Control Truck Fuel Consumed T1</td><td rowspan="2">Test Run 1 T/C Ratio</td><td rowspan="6">Test Segment Average T/C ratio (all T/C ratios within 2% band)</td></tr>
<tr><td>Test Truck Fuel Consumed T1</td></tr>
<tr><td>Control Truck Fuel Consumed T2</td><td rowspan="2">Test Run 2 T/C Ratio</td></tr>
<tr><td>Test Truck Fuel Consumed T2</td></tr>
<tr><td>Control Truck Fuel Consumed T3</td><td rowspan="2">Test Run 2 T/C Ratio</td></tr>
<tr><td>Test Truck Fuel Consumed T3</td></tr>
</table>

$$\%\ \mathbf{Improvement} = \frac{\mathbf{Ave.\ Baseline\ T/C\ Ratio - Ave.\ Test\ T/C\ Ratio}}{\mathbf{Ave.\ Test\ T/C\ Ratio}} \times \mathbf{100}$$

Although not required by the SAE J1321 procedure, two separate baseline segments were completed for the Army LTV and HTV evaluations. This was done to identify if any base vehicle efficiency shifts occurred during testing. One baseline was conducted at the start of testing, while the second was conducted at the end of testing. The general procedure was as follows:

- Baseline 1 (both test and control trucks using baseline oil)
- Test Segment 1 (test truck changed to candidate oil)
- Test Segment 2 (test truck changed to second candidate oil)
- Baseline 2 (both test and control trucks using baseline oil)

2.2 EVALUATED VEHICLES

For the light tactical wheeled category, fuel consumption testing was conducted using two up-armored M1151A1 HMMWV's. Table 2 outlines the technical data for the two HMMWV's used in the evaluation. For the heavy tactical wheeled category, testing was conducted using two M1070 HET's. Table 3 outlines the technical data for the two HET's used in the evaluation.

Table 2. LTV Technical Data, HMMWV, M1151A1

	Control Vehicle	Test Vehicle
Model	M1151A1	
Manufacturer	AM General	
VIN	313564	313685
Registration	NZ2A74	NZ2A8X
Manufacture Year	12/08	12/08
Designation	TRUCK 1	TRUCK 2
Test Start Mileage	2380.6	2496.3
Test Weight	≈13,000 lbs	≈13,000 lbs
Engine Information	General Engine Products (GEP) 6.5L(T) 190hp @ 3400RPM, 380lbft @ 1700RPM (diesel)	
Transmission	General Transmission Products (GTP) 4sp auto	
Front Axle	AM General Hypoid 3.08 Differential	
Rear Axle	AM General Hypoid 3.08 Differential (liquid cooled)	
Differential Ratio	3.08	
Wheel End Reduction	1.92	
Tires	37x12.50R16.5LT Good Year	
Wheel Base	130”	
Length	194”	
Width	91”	
Height	78.3”	

Table 3. HTV Technical Data, HET, M1070

	Control Vehicle	Test Vehicle
Model	M1070	
Manufacturer	Oshkosh	
VIN	10TGJ9Y46WS063202	10TGJ9Y4XWS063266
Registration	NU04W8	NU04Y4
Manufacture Year	7/11	02/98
Designation	TRUCK 1	TRUCK 2
Test Start Mileage	3748.5	11297.8
Test Start Hours	495.4	934.1
Overhaul SN	Y46WS063202	63266
Overhaul Date	7/11	2/8
Overhaul Location	RRAD	Oshkosh
Test Weight -Net	≈44,900 lbs	≈44,900 lbs
Engine Information	Detroit Diesel Corporation (DDC) 8V92TA 500hp @ 2100RPM, 1470lbft @ 2100RPM (diesel)	
Transmission	Allison CLT-754 5sp auto	
#1 Axle	Rockwell SVI 5 MRDIS-FC, planetary hub, 7.36:1 overall ratio	
#2 Axle	Rockwell SVI 5 MRTGS-FC, planetary hub, 7.36:1 overall ratio	
#3 Axle	Rockwell SVI 5 MRTGS-FC, planetary hub, 7.36:1 overall ratio	
#4 Axle	Rockwell SVI 5 MRDIS-FC, planetary hub, 7.36:1 overall ratio	
Differential Ratio	1.59:1	
Wheel End Reduction	4.63:1	
Tires	425/95R20 (16.00R20) Michelin	
Wheel Base	215 in	
Length	361.6 in	
Width	102 in (144 in mirrors extended)	
Height	140.1 in	

2.3 Vehicle Preparations

Prior to testing, all vehicles underwent routine servicing to ensure satisfactory vehicle condition. This process included (but was not limited to):

- Engine oil and filter change
- Transmission fluid and filter change
- Front and rear axle/differential fluid change
- Air and fuel filter change
- Wheel alignment
- Repair of any other noted deficiencies

In addition to the pre-test maintenance, each vehicle was also retrofitted with a secondary weigh tank fuel system to help facilitate testing. The secondary weigh tank system is plumbed in parallel with the vehicles original fuel system, and allows the vehicle operator to select whether the engines would be fueled from the vehicle's original system, or the secondary weigh tank system. During actual baseline or test laps, the engines would operate from the secondary weigh tank so that weight measurements of the tank before and after each lap could be used to determine actual mass based fuel consumed. At all other times the vehicle would operate from their original fuel system. Figure 1 and Figure 2 show the weigh tank system, and auxiliary fuel cooler and switching valves installed into the LTV. Figure 3 and Figure 4 show the weight tank system and auxiliary fuel cooler and switching valves installed into the HTV.

Figure 1. LTV Weigh Tank Attachment

Figure 2. LTV Secondary Fuel Cooler and Supply Plumbing

Figure 3. HTV Weigh Tank Attachment

Figure 4. HTV Secondary Fuel Cooler and Supply Plumbing

In addition to the above, the HTV's were also retrofitted with a remote throttle controller to allow switching between two different throttle inputs during operation. This allowed the use of the vehicles standard accelerator pedal during more transient type driving which required regular changes of throttle actuation by the vehicles operator, and use of the remote throttle box to provide a steady electronic throttle input during more steady state type condition. Utilizing the remote throttle signal during steady state testing improved run to run consistency and reduced driver fatigue. Figure 5 shows a photo of the overall instrumentation and controls mounted in the cabin of the HTV. Figure 6 shows the auxiliary throttle box installed, and Figure 7 shows the console used to switch between the factory and auxiliary fuel systems (an identical switching device was also installed in the LTV's).

Figure 5. HTV Instrumentation and Controls

Figure 6. HTV Auxiliary Throttle Box

Figure 7. HTV Fuel System Switching Controls

2.4 EVALUATED LUBRICANTS

Two candidate lubricants were provided by TARDEC for the SAE J1321 evaluations. The oils provided were identical to those used during earlier MTV testing [1,2]. Both of the candidates were synthetic based and had viscosities of 75W-90 and 75W-140 respectively. Candidate performance was compared against a common baseline fluid. This fluid was an SAE J2360 approved petroleum based 80W-90, also consistent with previous testing. Since the HTV and LTV testing was conducted over two different time periods, different batches of these products were used during each test. Table 4 lists the respective TFLRF internal tracking identities of the lubricants used. For the HTV testing (which occurred prior to the LTV work), both the baseline and 75W-90 candidates were made up of two previous batches due to limited availability at the time of testing.

Table 4. Lubricant Identification Numbers

	LTV, M1151A1 HMMWV	HTV, M1070 HET
Baseline Oil, 80W-90	LO330868	LO272251/LO310413
Candidate 1, 75W-90	LO332220	LO310410/LO278907
Candidate 2, 75W-140	LO332374	LO310412

Table 5 shows the general chemical and physical properties of the lubricants evaluated.

Table 5. General Lubricant Chemical & Physical Properties

Test	ASTM Method	Units	80W90	75W140	75W90
			LO272251	LO332374	LO332220
Elements	**D5185**				
Aluminum		ppm	<1	<1	<1
Antimony		ppm	<1	<1	<1
Barium		ppm	<1	<1	<1
Boron		ppm	236	224	151
Calcium		ppm	6	<1	3
Chromium		ppm	<1	<1	<1
Copper		ppm	<1	<1	<1
Iron		ppm	<1	<1	<1
Lead		ppm	<1	<1	<1
Magnesium		ppm	<1	<1	10
Manganese		ppm	<1	<1	<1
Molybdenum		ppm	<1	<1	<1
Nickel		ppm	<1	<1	<1
Phosphorus		ppm	947	1331	1812
Silicon		ppm	<1	<1	<1
Silver		ppm	<1	<1	<1
Sodium		ppm	<5	<5	<5
Tin		ppm	<1	<1	<1
Zinc		ppm	2	<1	2
Potassium		ppm	<5	<5	<5
Strontium		ppm	<1	<1	<1
Vanadium		ppm	<1	<1	<1
Titanium		ppm	<1	<1	<1
Cadmium		ppm	<1	<1	<1
Kinematic Viscosity	**D445**				
Test Temperature		°C	40	40	40
Viscosity		mm^2/s	135.62	178.28	87.27
Kinematic Viscosity	**D445**				
Test Temperature		°C	100	100	100
Viscosity		mm^2/s	14.54	24.43	13.97
Nitrogen Content	**D4629**	ppm	982.1	887.5	1516.8
Base Number (Buffer End Point)	**D4739**	mg KOH / g	1.43	1.62	1.86

2.5 TEST FACILITY

Testing was conducted at a remote facility in west Texas. The test track utilized consisted of three paved lanes, and had an overall length of 9 miles start to finish. A view of the track from an elevated observation area is shown in Figure 8.

Figure 8. Pecos Test Track

Across the 9 miles duration of the track, there is an approximate 46 foot change in elevation. An estimated elevation curve based on GPS data is shown below in Figure 9.

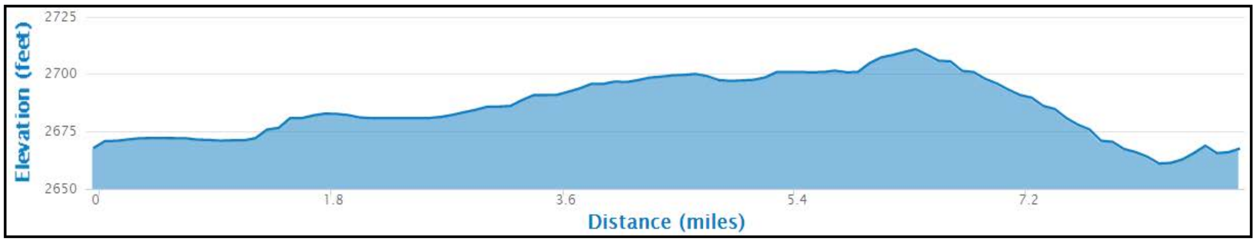

Figure 9. Test Track Approximate Elevation Profile

2.6 TEST CYCLES

Two different test cycles were used to determine changes in fuel consumption. These cycles were the same as those used during the previous MTV testing. The first was a two speed steady state or "highway cycle" where vehicles were operated for a set distance at constant speeds to simulate highway or convoy type operation. For the LTV, the two highway cycle speeds used were similar to those used in the past MTV testing. For the HTV, the highest speed portion was reduced to 40 mph to better accommodate the reduced top speed of the HET. Table 6 provides the operating speeds and distances for the highway cycle for each vehicle.

Table 6. Highway Test Cycle Description

LTV Operating Conditions	Vehicle Speed	Distance
1	25 mph (40.2 kph)	22.5 miles (36.2 km)
2	55 mph (88.5 kph)	22.5 miles (36.2 km)
HTV Operating Conditions	**Vehicle Speed**	**Distance**
1	25 mph (40.2 kph)	22.5 miles (36.2 km)
2	40 mph (64.4 kph)	22.5 miles (36.2 km)

The second cycle was a transient or "city cycle" used to simulate a combination of stop-and-go driving and limited duration medium and high speed operation. This test cycle was based on two published cycles in SAE J1376, the "Local Test Cycle" and "Short Haul Test Cycle" (distances were modified to suit the 9-mile track). Details on the transient test cycle are provided in Table 7 and Figure 10 (Note: In instances where two "Idle" steps occurred in the series, one was eliminated from the overall route. Consistent with the highway cycle, the 55 mph steps were reduced to 40 mph for the HTV).

Table 7. Transient Test Cycle Description

Step	Maneuver	Total Distance (miles)	Cycle Type
0	Start Engine	0.00	SAE J1376 Local Test Cycle #1
1	30 Second Idle	0.00	
2	Accelerate to and hold 5 mph	0.15	
3	Accelerate to and hold 10 mph	0.48	
4	Decelerate to 0 mph	0.49	
5	20 Second Idle	-	
6	Accelerate to and hold 20 mph	0.97	
7	Decelerate to 0 mph	1.00	
8	20 Second Idle	-	
9	Accelerate to and hold 30 mph	1.44	
10	Decelerate to 0 mph	1.50	
11	20 Second Idle	-	
12	Accelerate to and hold 35 mph	1.92	
13	Decelerate to 0 mph	2.00	
14	20 Second Idle	-	
15	Accelerate to and hold 25 mph	2.56	
16	Decelerate to 0 mph	2.60	
17	20 Second Idle	-	
18	Accelerate to and hold 15 mph	2.98	
19	Decelerate to 0 mph	3.00	
20	20 Second Idle	-	
21	Repeat Steps 2-20	6.00	SAE J1376 Local Cycle #2
22	Repeat Steps 2-19	9.00	SAE J1376 Local Cycle #3
23	60 Second Idle	-	SAE J1376 Short Haul Cycle #1
24	Accelerate to and hold 25 mph	15.00	
25	Accelerate to and hold 35 mph	21.00	
26	Accelerate to and hold 55 mph	27.00	
27	Decelerate to and hold 25 mph	33.00	SAE J1376 Short Haul Cycle #2
28	Accelerate to and hold 35 mph	39.00	
29	Accelerate to and hold 55 mph	44.80	
30	Decelerate to 0 mph	45.00	
31	60 Second Idle	-	
32	Shut off Engine	-	

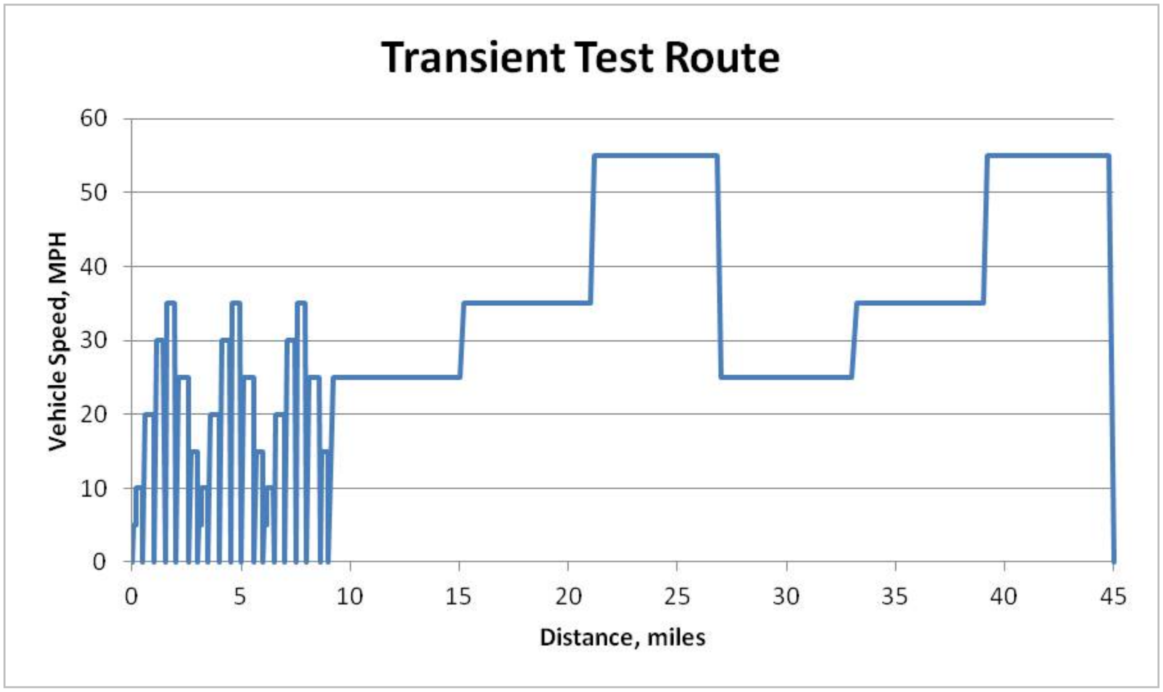

Figure 10. Transient Test Cycle Plot

Although the distance of both of these test cycles meet the previous 1986 revision of the SAE J1321 procedure for required total distance, they both fall 5 miles short of the 2012 revisions minimum of 50 miles to be considered official SAE J1321 tests. For sake of maintaining comparison to previous work, the cycle length was not adjusted and remained at 45 miles.

3.0 RESULTS

The following sections summarize the results of the LTV and HTV fuel consumption evaluations. Complete test reports and data sets from the SwRI fleet team can be found in the attached appendices.

3.1 Light Tactical Wheeled Vehicle

Table 8 shows the actual mass based fuel consumption values, the resulting lap T/C ratios, and the average segment T/C ratios used in the fuel consumption calculations for each of the baseline and test segments of the LTV evaluation.

Table 8. LTV Fuel Consumed and T/C Ratios

Baseline #1 (Highway)					
Run #1		Run #2		Run #3	
Fuel Consumed by Test Vehicle 27.55 lbs.	Fuel Consumed by Control Vehicle 27.45 lbs.	Fuel Consumed by Test Vehicle 27.40 lbs.	Fuel Consumed by Control Vehicle 27.45 lbs.	Fuel Consumed by Test Vehicle 27.50 lbs.	Fuel Consumed by Control Vehicle 27.65 lbs.
Baseline (Highway) T/C Ratio #1 1.0036		Baseline (Highway) T/C Ratio #2 0.9982		Baseline (Highway) T/C Ratio #3 0.9946	
Average T/C Ratio for Baseline (Highway) Segment 0.9988					
Baseline #1 (City)					
Run #1		Run #2		Run #3	
29.25 lbs.	29.50 lbs.	29.70 lbs.	29.65 lbs.	30.95 lbs.	31.25 lbs.
0.9915		1.0017		0.9904	
0.9945					
Test Oil #1 (Highway)					
Run #1		Run #2		Run #3	
29.55 lbs.	29.85 lbs.	28.25 lbs.	28.45 lbs.	27.70 lbs.	27.95 lbs.
0.9899		0.9930		0.9911	
0.9913					
Test Oil #1 (City)					
Run #1		Run #2		Run #3	
29.10 lbs.	29.80 lbs.	29.10 lbs.	29.75 lbs.	30.10 lbs.	30.95 lbs.
0.9765		0.9782		0.9725	
0.9757					
Test Oil #2 (Highway)					
Run #1		Run #2		Run #3	
28.40 lbs.	28.90 lbs.	27.90 lbs.	28.35 lbs.	27.45 lbs.	27.80 lbs.
0.9827		0.9841		0.9874	
0.9847					
Test Oil #2 (City)					
Run #1		Run #2		Run #3	
29.30 lbs.	30.20 lbs.	29.05 lbs.	29.85 lbs.	30.00 lbs.	30.75 lbs.
0.9702		0.9732		0.9756	
0.9730					
Baseline #2 (Highway)					
Run #1		Run #2		Run #3	
28.10 lbs.	28.10 lbs.	27.60 lbs.	27.35 lbs.	27.75 lbs.	27.65 lbs.
1.0000		1.0091		1.0036	
1.0043					
Baseline #2 (City)					
Run #1		Run #2		Run #3	
29.85 lbs.	29.25 lbs.	30.65 lbs.	30.20 lbs.	30.95lbs	30.45 lbs.
1.0205		1.0149		1.0164	
1.0173					

Table 9 shows the final tabulated fuel consumption improvement values and applicable confidence intervals for each of the test oils compared to two baseline segements. Cells shown in grey identify non-statistically significant results. Cells shown in green identify statistically signficiant fuel consumption improvement. As shown, all but one comparision yeilds statistically improved fuel consumption for the LTV. Although not statistically significant, the comparison for baseline #1 vs. test oil #1 for the highway cycle shows an indication of improvement similar to the other results.

Table 9. LTV Results

Baseline 1 (80W90) vs. Test Oil 1 (75W90)	Highway Route		Nominal	Confidence Interval
		Fuel Saved	0.75 %	± 0.77 %
		Improvement	0.75 %	± 0.78 %
	Transient Route		Nominal	Confidence Interval
		Fuel Saved	1.89 %	± 1.1 %
		Improvement	1.83 %	± 1.13 %
Baseline 1 (80W90) vs. Test Oil 2 (75W140)	Highway Route		Nominal	Confidence Interval
		Fuel Saved	1.41 %	± 0.83 %
		Improvement	1.43 %	± 0.84 %
	Transient Route		Nominal	Confidence Interval
		Fuel Saved	2.17 %	± 1.09 %
		Improvement	2.21 %	± 1.12 %
Baseline 2 (80W90) vs. Test Oil 1 (75W90)	Highway Route		Nominal	Confidence Interval
		Fuel Saved	1.29 %	± 0.77 %
		Improvement	1.3 %	± 0.78 %
	Transient Route		Nominal	Confidence Interval
		Fuel Saved	4.08 %	± 0.65 %
		Improvement	4.26 %	± 0.67 %
Baseline 2 (80W90) vs. Test Oil 2 (75W140)	Highway Route		Nominal	Confidence Interval
		Fuel Saved	1.94 %	± 0.83 %
		Improvement	1.98 %	± 0.85 %
	Transient Route		Nominal	Confidence Interval
		Fuel Saved	4.35 %	± 0.63 %
		Improvement	4.55 %	± 0.65 %

As seen, a greater benefit in fuel consumption improvement was observed during the city type driving cycle, yielding approximately two times the improvement for a given set of oils over the steady state highway type driving cycle. This result is consistent with trends seen during the past MTV testing. Different however is the improved fuel consumption observed with the 75W-140 in

the LTV, whereas past MTV testing showed a trend of decreased fuel efficiency with the increased viscosity. It is expected that this change can be attributed to the overall hardware size and resulting lubricant capacities between the MTV and LTV vehicles, and differences in internal unit loading (or load normalized against hardware size) of the differentials.

In regards to lubricant capacity, the HMMWV's differential has an internal capacity of approximately 2 quarts, which is much smaller than the MTV capacity of approximately 20 quarts. This reduces the detriment to the HMMWV from the higher viscosity 75W-140 with respect to churning losses, as the volume of oil being churned during operation is much lower than that present in the larger MTV. With the churning losses reduced, other benefits from the heavier 75W-140 can start to be realized. The up-armored M1151A1 is the latest variant in the HMMWV family, and has a significantly increased mass compared to many earlier variants. AM General states the gross vehicle weight rating (GVWR) of the M1151A1 at 13,500 lbs. This is up considerably from earlier variants such as the M998 with a GVWR of only 7,700 lbs. Despite the increased mass of the later model HMMWV's, the overall driveline hardware size has remained largely consistent, and is considered at a high level as light duty compared to the larger MTV and HTV vehicles. With the increased vehicle mass it must now move, the unit loading of the LTV's drivetrain has increased significantly relative to its size, and thus yields higher contact loading (i.e. unit loading) in the differential gear set during operation. It is expected that with these higher contact loads, the thicker 75W-140 is allowing for lower frictional losses due to the increased film thickness and better separation of surface asperities in the gear mesh. It is expected that these two trends combined are what is allowing the LTV to see benefit from the heaver 75W-140, unlike that previously seen in the MTV testing.

Another trend identified in the HMMWV data was differences in calculated fuel consumption changes when comparing to the first or second baseline segments. In general, comparison with baseline #2 predicts approximately two times the improvement then when compared to baseline #1. This indicates some base efficiency shift occurred during the LTV's duration of testing. The exact cause of this shift is unknown, but it is likely attributed to the relatively low starting mileage of the HMMWV's used for testing, which allowed some overall new engine/driveline break-in effects to influence data over the course of testing. In addition, laboratory axle efficiency testing

typically demonstrates additional break-in and resulting efficiency shift of axles occurring when introduced to lower viscosity lubricants. Despite the differing predicted results when comparing between baseline #1 or #2, a clear improvement trend is realized for the LTV.

3.2 HEAVY TACTICAL WHEELED VEHICLE

Table 10 and Table 11 show the actual mass based fuel consumption values, the resulting lap T/C ratios, and the average segment T/C ratios used in the fuel consumption calculations for each of the baseline and test segments of the HTV evaluation.

Table 10. HTV Fuel Consumed and T/C Ratios

Baseline #1 (Highway)					
Run #1		Run #2		Run #3	
Fuel Consumed by Test Truck 64.30 lbs.	Fuel Consumed by Control Truck 68.40 lbs.	Fuel Consumed by Test Truck 63.35 lbs.	Fuel Consumed by Control Truck 67.50 lbs.	Fuel Consumed by Test Truck 62.90 lbs.	Fuel Consumed by Control Truck 66.80 lbs.
Baseline (Highway) T/C Ratio #1 0.9401		Baseline (Highway) T/C Ratio #2 0.9385		Baseline (Highway) T/C Ratio #3 0.9416	
Average T/C Ratio for Baseline (Highway) Segment 0.9401					
Baseline #1 (City)					
Run #1		Run #2		Run #3	
70.30 lbs.	74.05 lbs.	69.15 lbs.	73.35 lbs.	68.20 lbs.	72.95 lbs.
0.9494		0.9427		0.9349	
0.9423					
Test Oil #2 (Highway)					
Run #1		Run #2		Run #3	
66.40 lbs.	69.25 lbs.	65.70 lbs.	68.60 lbs.	64.40 lbs.	67.30 lbs.
0.9588		0.9577		0.9569	
0.9578					
Test Oil #2 (City)					
Run #1		Run #2		Run #3	
71.75 lbs.	74.55 lbs.	70.10 lbs.	72.45 lbs.	69.55 lbs.	71.35 lbs.
0.9624		0.9676		0.9748	
0.9683					
Test Oil #1 (Highway)					
Run #1		Run #2		Run #3	
62.55 lbs.	66.85 lbs.	61.45 lbs.	65.85 lbs.	61.50 lbs.	65.75 lbs.
0.9357		0.9332		0.9354	
0.9347					

Table 11. HTV Fuel Consumed and T/C Ratios (cont.)

Test Oil #1 (City)					
Run #1		Run #2		Run #3	
67.80 lbs.	73.00 lbs.	67.20 lbs.	71.95 lbs.	68.55 lbs.	72.60 lbs.
0.9288		0.9340		0.9442	
0.9357					
Baseline #2 (Highway)					
Run #1		Run #2		Run #3	
61.90 lbs.	65.60 lbs.	61.30 lbs.	63.95 lbs.	61.20 lbs.	65.15 lbs.
0.9436		0.9586		0.9394	
0.9472					
Baseline #2 (City)					
Run #1		Run #2		Run #3	
70.04 lbs.	73.65 lbs.	69.55 lbs.	72.80 lbs.	67.75 lbs.	71.75 lbs.
0.9559		0.9554		0.9443	
0.9518					

Table 12 shows the final tabulated fuel consumption changes and applicable confidence intervals for each of the test oils compared to baseline #1 and baseline #2. Cells shown in grey identify non-statistically significant results. Cells shown in green identify statistically signficiant fuel consumption improvement. Cells shown in red identify statistically signficiant fuel consumption detriment.

Table 12. HTV Results

Comparison	Route		Nominal	Confidence Interval
Baseline 1 (80W90) vs. Test Oil 1 (75W90)	Highway Route	Fuel Saved	0.57 %	± 0.35 %
		Improvement	0.57 %	± 0.35 %
	Transient Route	Fuel Saved	0.71 %	± 1.82 %
		Improvement	0.71 %	± 1.83 %
Baseline 1 (80W90) vs. Test Oil 2 (75W140)	Highway Route	Fuel Saved	-1.89 %	± 0.31 %
		Improvement	-1.85 %	± 0.31 %
	Transient Route	Fuel Saved	-2.75 %	± 1.62 %
		Improvement	-2.68 %	± 1.58 %
Baseline 2 (80W90) vs. Test Oil 1 (75W90)	Highway Route	Fuel Saved	1.31 %	± 2.58 %
		Improvement	1.33 %	± 2.62 %
	Transient Route	Fuel Saved	1.70 %	± 1.72 %
		Improvement	1.73 %	± 1.75 %
Baseline 2 (80W90) vs. Test Oil 2 (75W140)	Highway Route	Fuel Saved	-1.12 %	± 2.61 %
		Improvement	-1.11 %	± 2.58 %
	Transient Route	Fuel Saved	-1.73 %	± 1.52 %
		Improvement	-1.70 %	± 1.49 %

Consistent with previous trends observed in the MTV testing, the 75W-140 showed a statistically significant detriment to fuel consumption in all calculations except that for the baseline #2 highway route, which although not statistically signficiant, still showed an indication of increased consumption. For the 75W-90, a statistically significant improvement was observed on the baseline #1 highway route, but only an indication of improvement was seen for all other comparisons. Like the HMMWV testing comparisoin between baseline #1 or baseline #2 yeilds some slighly different results, but overall not to the same magnitude of that seen in the HMMWV data.

4.0 CONCLUSIONS

Based upon the measured changes in fuel consumption for the LTV and HTV evaluations, there appears to be real world fuel consumptions savings associated with utilization of select driveline fluids. However based on hardware size, optimum fluids for maximum efficiency improvement may not be the same. During this testing it was found that the LTV showed in improvement in fuel consumption with both the tested 75W-90 and 75W-140 candidate lubricants, with largest gains being realized in the more transient “city cycle”. This was a slight departure from results seen in past MTV testing [1,2] which showed improvements in fuel consumption with the lower 75W-90 viscosity oil, and detriment with the higher viscosity 75W-140. This differing result is attributed to the smaller oil sump capacity limiting detriment from churning losses, and higher unit loading of the driveline in the LTV which allows for increased film thickness of the 75W-140 to provide reduced internal friction. Similar to the past MTV results, the larger HTV generally supported that the heavier viscosity 75W-140 provided a detriment to fuel consumption on both the transient and highway driving cycles, while the lighter 75W-90 showed a trend towards improved fuel consumption. Several of the HTV results did not exceed the calculated statistical confidence intervals required to confidently claim improved or reduced fuel consumption, but all data was found to trend consistently with those that did show statistically confident results.

5.0 RECOMMENDATIONS

It is recommended that testing on a stationary axle efficiency stand be conducted to further explore the possibility of axle efficiency improvement and reduced vehicle fuel consumption through optimization of driveline lubricants. In particular, testing at higher input pinion loads should be considered for the MTV and HTV axles to determine if improved efficiency from the 75W-140 can be realized with higher loading. In addition, a test matrix with a wide range of candidate viscosities should be conducted to determine hardware size versus efficiency response. This testing would help to further explore the relationship of driveline mechanical efficiency as a function of lubricant viscosity, unit loading, and overall hardware size.

6.0 REFERENCES

1. Warden, R.W., Frame, E.A., Brandt, A. C., "SAE J1321 Testing Using M1083A1 FMTVS", Interim Report TFLRF No. 404, March 2010.
2. Warden, R.W., Frame, E.A., "Axle Lubricant Efficiency", Interim Report TFLRF No. 444, May 2014
3. Fuel Consumption Test Procedure - Type II, J1321, 2012

APPENDIX A. LTV Test Report

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FUELS AND LUBRICANTS RESEARCH DIVISION
Fuels and Driveline Lubricants Research Department

Report On:

"SAE J1321 Fuel Consumption Test Program on AM General M1151A1W/B1 Vehicles"

Conducted For:

The US Army

AM General High Mobility Multipurpose Wheeled Vehicle (HMMWV)
Baseline Oil: LO-330868
Test Oil 1: LO-332220
Test Oil 2: LO-332374

February 17, 2016

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SOUTHWEST RESEARCH INSTITUTE

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APPENDICES

I. INTRODUCTION

At the request of The US Army, Southwest Research Institute (SwRI®) conducted a fuel economy test utilizing two AM General High Mobility Multipurpose Wheeled Vehicle (HMMWV). The purpose of the testing was to compare the fuel economy benefits derived from using different differential lubricants.

The procedure chosen for this evaluation was a modified version of the February 2012 revision of the SAE J1321 *"Fuel Consumption Test Procedure - Type II"*. This recommended practice provided a standardized test procedure for comparing the in-service fuel consumption of a vehicle operated under two conditions. An unchanging control vehicle ran in tandem with a test vehicle to provide reference fuel consumption data. The fuel consumption was measured by using weigh tanks.

A baseline segment was first conducted followed by a test segment for each differential lubricant. Finally an additional baseline segment was conducted to confirm results. The HMMWVs were operated over both a simulated "highway" and "city" route at a closed test track.

II. TEST PLAN

A. Description of Vehicles

The US Army provided the vehicles used for testing during this program.

The HMMWVs were identical vehicles equipped with General Engine Products engines rated at 190 hp and General Transmission Products automatic transmissions. The vehicles were unloaded during testing with a tractor weight of approximately 13,600 lbs.

B. Vehicle Preparation

Prior to commencing with testing the following preparations were made to the vehicles.

1. All wheels were aligned.
2. The engine air filters and fuel filters were replaced.
3. The engine, transmission, and transfer case fluids were changed.
4. A separate weigh tank was connected to each vehicle's fuel system via a three-way valve to permit operation either from the vehicle's fuel supply or from the weigh tank.
5. Each vehicle was equipped with a Campbell CR-3000 datalogger to record GPS position and speed, all differential temperatures, engine oil sump temperature, transfer case temperature, transmission temperature, and pedal voltage. All fluid temperatures were measured by placing a thermocouple through a modified drain plug. The data was recorded at one second intervals.
6. An electronic master switch was connected to a time counter and to the datalogger. The switch was turned on at the beginning of each run and turned off at the end of each run.

7. Practice laps were conducted to establish target times at markers on each route. The target times were specific to the driver and the vehicle. During the testing phase, the lap time was required to be within +/-0.25% of the target time to be considered operationally valid.

C. Test Routes (Vehicle Driving Cycle)

Fuel consumption was measured using simulated “highway” and “city” routes on a closed test track. The “highway” route was conducted at 25 mph for 22.5 miles and 55 mph for 22.5 miles. The “city” route was a transient route adapted from the SAE J1376 Procedure. Both routes were 45 miles long which is 5 miles short of what is required by the SAE J1321 (Revision 2012-02). These routes were chosen to keep consistency with historical test data. A GPS based driver assist route trace program was used by the drivers to help to maintain route constancy and lap times. Additionally, the weather conditions set by the SAE J1321 (Revision 2012-02) were not met on all runs. The maximum wind speed and variation in wind speeds limits were exceeded. Due to the slower than typical vehicle speeds (< 60 mph) and an already modified procedure (< 50 mile route) the Army agreed that the weather parameters would not be used to determine lap validity. All weather data collected is included in Appendix A.

Table 1. Highway Route Maneuvers

Step	Maneuver	Total Distance (miles)
0	Hold 25 mph	0.00-22.50
1	Accelerate to and hold 55 mph	22.50-45.00
2	Switch off weigh tank	45.00

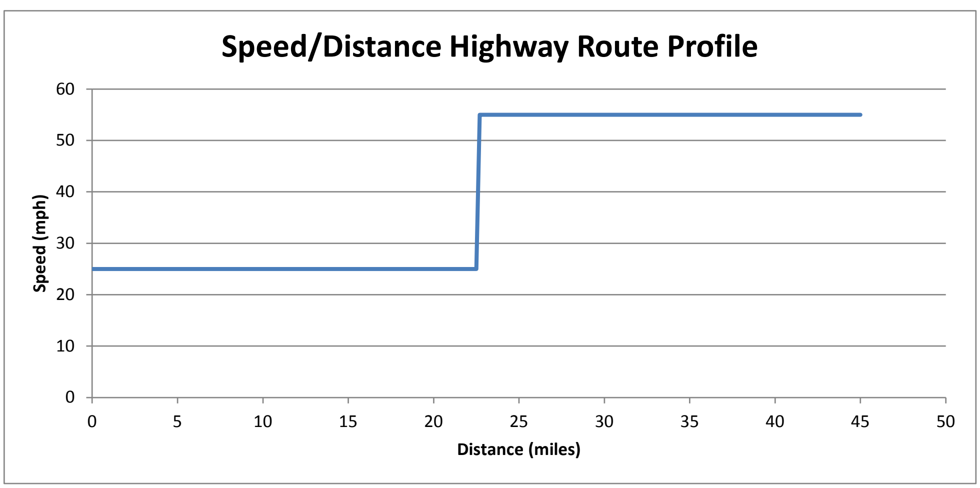


Figure 1. Highway Route Profile

Table 2. City Route Maneuvers

Step	Maneuver	Total Distance
0	Start Engine	0.00
1	30 Second Idle	0.00
2	Accelerate to and hold 5 mph	0.15
3	Accelerate to and hold 10 mph	0.48
4	Deccelerate to 0mph	0.49
5	20 Second Idle	-
6	Accelerate to and hold 20 mph	0.97
7	Deccelerate to 0mph	1.00
8	20 Second Idle	-
9	Accelerate to and hold 30 mph	1.44
10	Deccelerate to 0mph	1.50
11	20 Second Idle	-
12	Accelerate to and hold 35 mph	1.92
13	Deccelerate to 0mph	2.00
14	20 Second Idle	-
15	Accelerate to and hold 25 mph	2.56
16	Deccelerate to 0mph	2.60
17	20 Second Idle	-
18	Accelerate to and hold 15 mph	2.98
19	Deccelerate to 0mph	3.00
20	20 Second Idle	-
21	Repeat Steps 2-20	6.00
22	Repeat Steps 2-19	9.00
23	60 Second Idle	-
24	Accelerate to and hold 25 mph	15.00
25	Accelerate to and hold 35 mph	21.00
26	Accelerate to and hold 55 mph	27.00
27	Decelerate to and hold 25 mph	33.00
28	Accelerate to and hold 35 mph	39.00
29	Accelerate to and hold 55 mph	44.80
30	Deccelerate to 0 mph	45.00
31	60 Second Idle	-
32	Shut off Engine	-

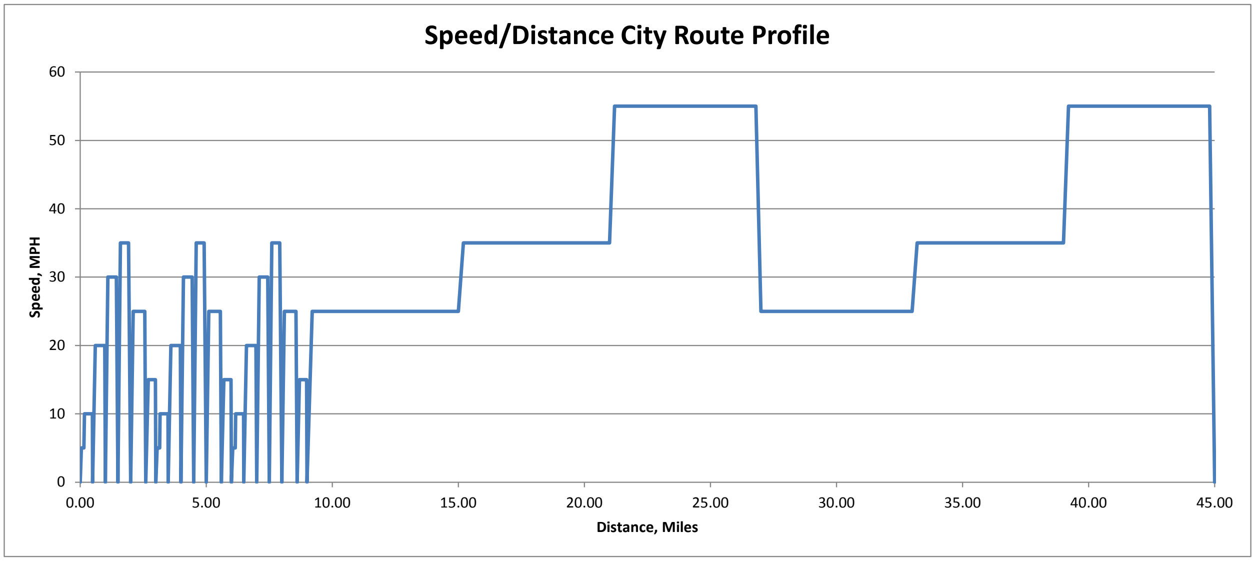


Figure 2. City Route Profile

D. Test Matrix

The test matrix consisted of eight segments, each of which consisted of three valid runs. Both vehicles were operated simultaneously for each run. Baseline differential fluid (LO330868) was used in the control vehicle (Vehicle 01) for all segments. Two test differential fluids (LO332220 & LO332374, respectively) were evaluated in the test vehicle (Vehicle 02) for the test segments. A double flush was performed when changing differential fluids in the test vehicle. A single drain and fill was performed on the control vehicle each time the test vehicle fluid was changed. Each flush consisted of driving the vehicle for 15 minutes, draining the differential fluid from the 4 axles and 8 hubs, and then adding the new differential fluid. A description of the test matrix is shown in Table 3.

Table 3. Test Matrix

Differential Fluid	Segment	Lap
Truck 01 Double Flush to LO330868	Baseline #1 Highway	Highway Lap #1
		Highway Lap #2
		Highway Lap #3
Truck 02 Double Flush to LO330868	Baseline #1 City	City Lap #1
		City Lap #2
		City Lap #3
Truck 01 Drain and Fill to LO330868	Test #1 Highway	Highway Lap #1
		Highway Lap #2
		Highway Lap #3
Truck 02 Double Flush to LO332220	Test #1 City	City Lap #1
		City Lap #2
		City Lap #3
Truck 01 Drain and Fill to LO330868	Test #2 Highway	Highway Lap #1
		Highway Lap #2
		Highway Lap #3
Truck 02 Double Flush to LO332374	Test #2 City	City Lap #1
		City Lap #2
		City Lap #3
Truck 01 Drain and Fill to LO330868	Baseline #2 Highway	Highway Lap #1
		Highway Lap #2
		Highway Lap #3
Truck 02 Double Flush to LO330868	Baseline #2 City	City Lap #1
		City Lap #2
		City Lap #3

The weather data collected during the segments was obtained from a portable weather station set on the interior of the track. The weather data includes: air temperature, wind speed, and relative humidity. No weather corrections were performed on the fuel economy data. The SAE J1321 (Revision 2012-02) Recommended Practice establishes weather limits for testing including limits in wind and temperature variation for each run, segment, and overall test. Due to the slower than typical vehicle speeds (< 60 mph) and an already modified procedure (< 50 mile route) the Army agreed that the weather parameters would not be used to determine lap validity. Collected weather data can be found in Appendix A along with the constraints set by the SAE J1321 (Revision 2012-02) Recommended Practice.

Each day prior to running the route, tire inflation pressures were checked and adjusted to the proper level. The vehicles then performed a 1 hour warm-up as recommended by the SAE J1321 (Revision 2012-02) Recommended Practice. Additional inspections were performed on the vehicle prior to start, after warm-up, between test runs, and at the end of each day. This standard practice was performed to ensure validity in each vehicle test run.

III. TEST RESULTS

Each lap of testing resulted in a ratio of the fuel used by the Test Vehicle to the Control Vehicle (T/C ratio). A minimum of three T/C ratios were required for each segment. The resulting T/C ratios were used to calculate the fuel saved and the fuel improvement when comparing the baseline and test segments. Additionally, the T/C ratios were used to determine a 95% confidence interval for each result per the J1321 procedure. Only valid laps were considered in the analysis of the fuel consumption data. A lap was considered valid if the lap time fell within 0.25% of the first baseline run for the vehicle and the first baseline run time could also not differ more than 0.50% between Vehicle 01 and Vehicle 02. A summary of the resulting T/C ratios can be seen in Table 4. The T/C ratios and lap times are shown in Appendix B. Both test segments are compared to the first and second baseline segment. A summary of the test results are shown in Table 5 and Figures 3 and 4.

Table 4: Resulting T/C Ratios

Baseline #1 (Highway)					
Run #1		Run #2		Run #3	
Fuel Consumed by Test Vehicle 27.55 lbs.	Fuel Consumed by Control Vehicle 27.45 lbs.	Fuel Consumed by Test Vehicle 27.40 lbs.	Fuel Consumed by Control Vehicle 27.45 lbs.	Fuel Consumed by Test Vehicle 27.50 lbs.	Fuel Consumed by Control Vehicle 27.65 lbs.
Baseline (Highway) T/C Ratio #1 1.0036		Baseline (Highway) T/C Ratio #2 0.9982		Baseline (Highway) T/C Ratio #3 0.9946	
Average T/C Ratio for Baseline (Highway) Segment 0.9988					
Baseline #1 (City)					
Run #1		Run #2		Run #3	
29.25 lbs.	29.50 lbs.	29.70 lbs.	29.65 lbs.	30.95 lbs.	31.25 lbs.
0.9915		1.0017		0.9904	
0.9945					
Test Oil #1 (Highway)					
Run #1		Run #2		Run #3	
29.55 lbs.	29.85 lbs.	28.25 lbs.	28.45 lbs.	27.70 lbs.	27.95 lbs.
0.9899		0.9930		0.9911	
0.9913					
Test Oil #1 (City)					
Run #1		Run #2		Run #3	
29.10 lbs.	29.80 lbs.	29.10 lbs.	29.75 lbs.	30.10 lbs.	30.95 lbs.
0.9765		0.9782		0.9725	
0.9757					
Test Oil #2 (Highway)					
Run #1		Run #2		Run #3	
28.40 lbs.	28.90 lbs.	27.90 lbs.	28.35 lbs.	27.45 lbs.	27.80 lbs.
0.9827		0.9841		0.9874	
0.9847					
Test Oil #2 (City)					
Run #1		Run #2		Run #3	
29.30 lbs.	30.20 lbs.	29.05 lbs.	29.85 lbs.	30.00 lbs.	30.75 lbs.
0.9702		0.9732		0.9756	
0.9730					

Table 4: Resulting T/C Ratios Continued

Baseline #2 (Highway)					
Run #1		Run #2		Run #3	
28.10 lbs.	28.10 lbs.	27.60 lbs.	27.35 lbs.	27.75 lbs.	27.65 lbs.
1.0000		1.0091		1.0036	
1.0043					
Baseline #2 (City)					
Run #1		Run #2		Run #3	
29.85 lbs.	29.25 lbs.	30.65 lbs.	30.20 lbs.	30.95lbs	30.45 lbs.
1.0205		1.0149		1.0164	
1.0173					

Table 5. Baseline #1 and #2 vs. Test Oil #1 and #2 Test Results

Baseline #1 vs. Test Oil #1	Highway Route		Nominal	Confidence Interval	
		Fuel Saved	0.75%	±	0.77%
		Improvement	0.75%	±	0.78%
	City Route		Nominal	Confidence Interval	
		Fuel Saved	1.89%	±	1.10%
		Improvement	1.93%	±	1.13%
Baseline #1 vs. Test Oil #2	Highway Route		Nominal	Confidence Interval	
		Fuel Saved	1.41%	±	0.83%
		Improvement	1.43%	±	0.84%
	City Route		Nominal	Confidence Interval	
		Fuel Saved	2.17%	±	1.09.%
		Improvement	2.21%	±	1.12%
Baseline #2 vs. Test Oil #1	Highway Route		Nominal	Confidence Interval	
		Fuel Saved	1.29%	±	0.77%
		Improvement	1.30%	±	0.78%
	City Route		Nominal	Confidence Interval	
		Fuel Saved	4.08%	±	0.65%
		Improvement	4.26%	±	0.67%
Baseline #2 vs. Test Oil #2	Highway Route		Nominal	Confidence Interval	
		Fuel Saved	1.94%	±	0.83%
		Improvement	1.98%	±	0.85%
	City Route		Nominal	Confidence Interval	
		Fuel Saved	4.35%	±	0.63%
		Improvement	4.55%	±	0.65%

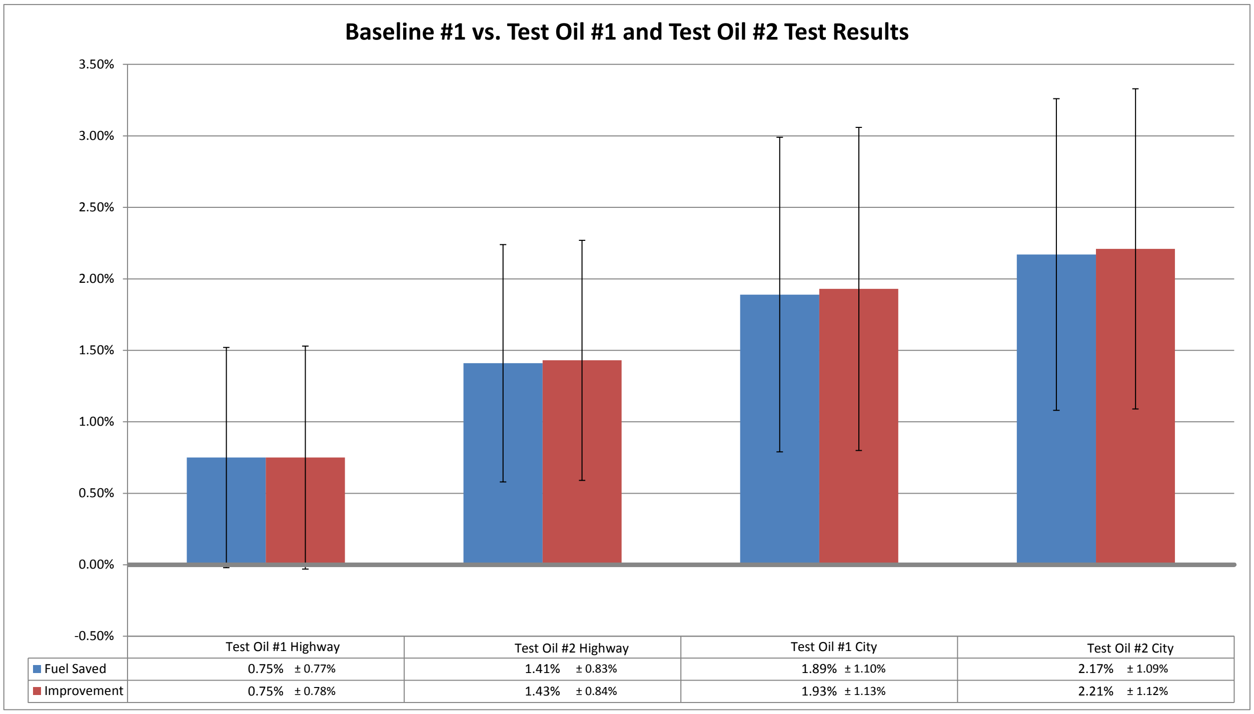


Figure 3. Test Results

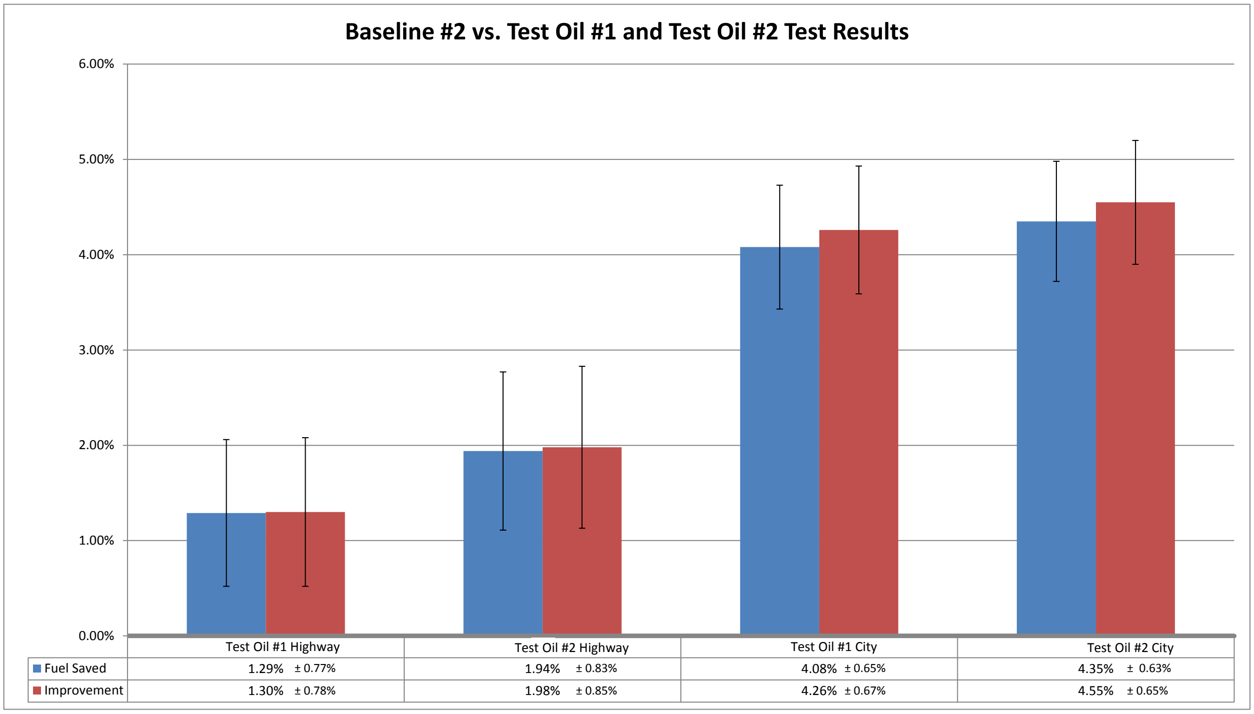


Figure 4. Test Results

Appendix A
Weather Data

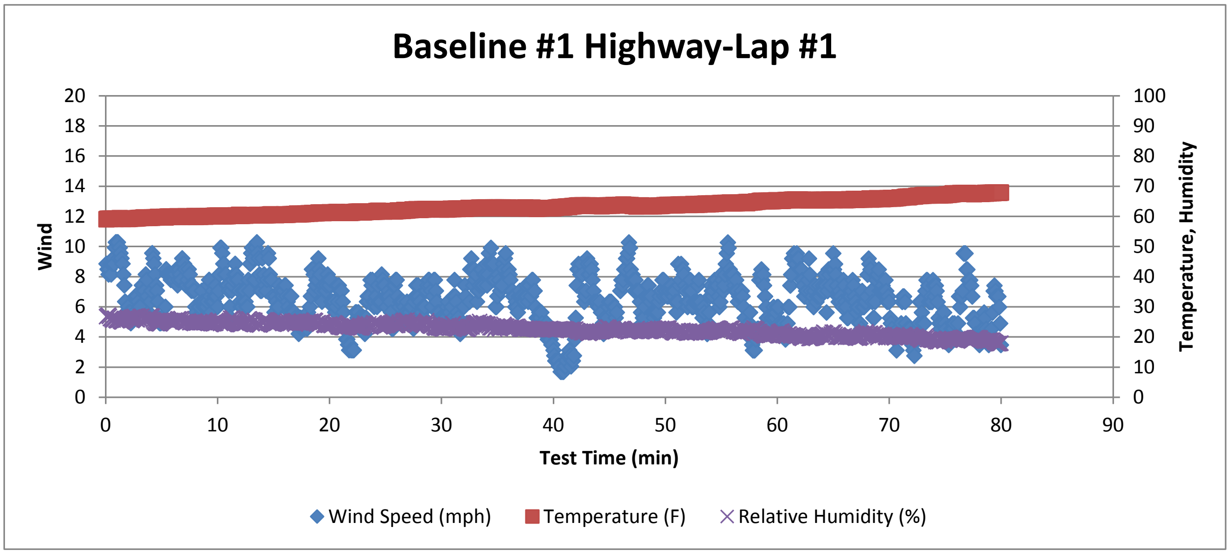
Test #1 Highway Weather Data Summary
Baseline #1 Highway Segment and Test Oil #1 Highway Segment

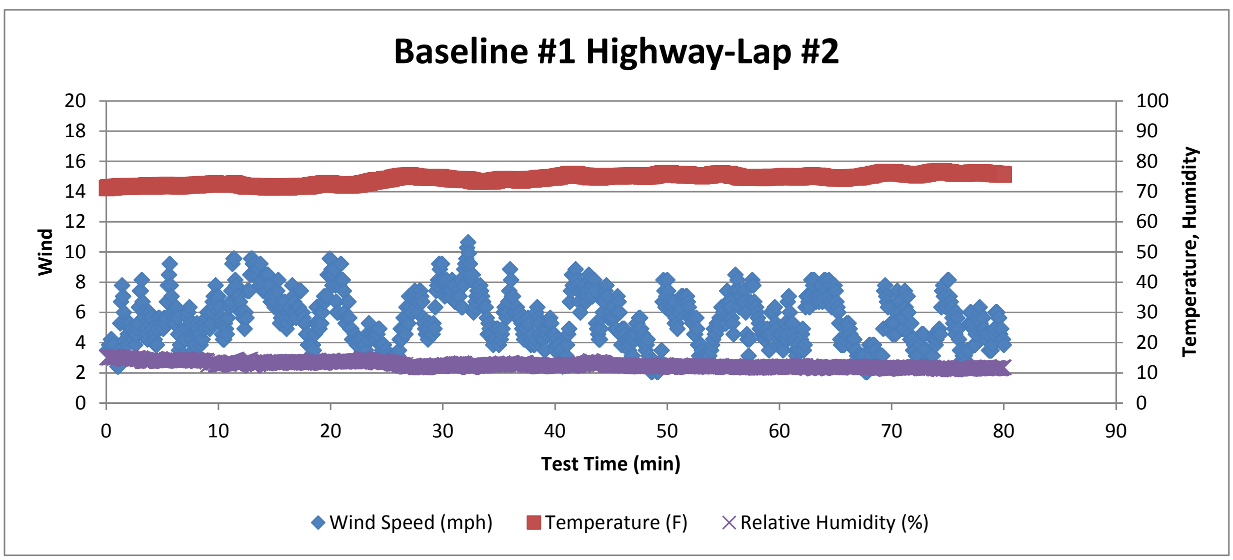
Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	6.49	1.70	10.28	---	59.09	68.01	8.92	22.70
Run #2	5.47	2.06	10.64	1.02	71.20	76.80	5.60	12.67
Run #3	5.21	0.63	8.85	1.28	52.26	65.14	12.88	35.35
Segment	5.72	0.63	10.64	1.28	52.26	76.80	24.54	23.57
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

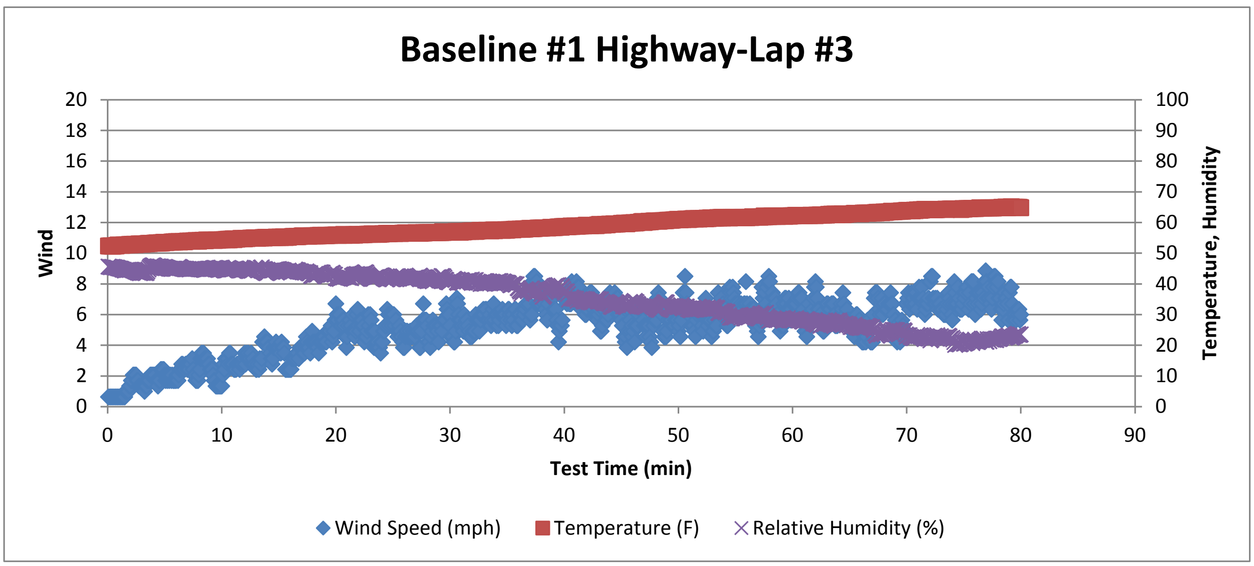
Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	5.08	2.06	8.14	---	34.75	45.66	10.91	34.90
Run #2	4.85	1.35	10.28	0.24	48.23	59.94	11.71	22.65
Run #3	3.22	0.99	8.14	1.86	64.70	69.96	5.26	12.86
Segment	4.38	0.99	10.28	1.86	34.75	69.96	35.21	23.47
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

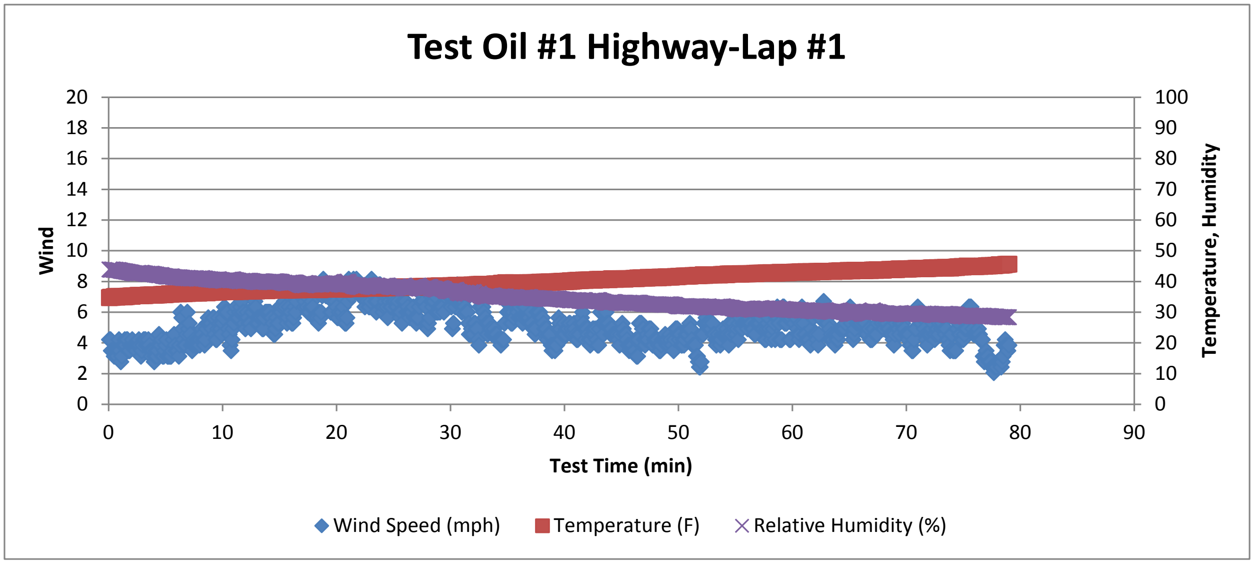
Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	5.05	0.63	10.64	3.26	34.75	76.80	42.05	23.52
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

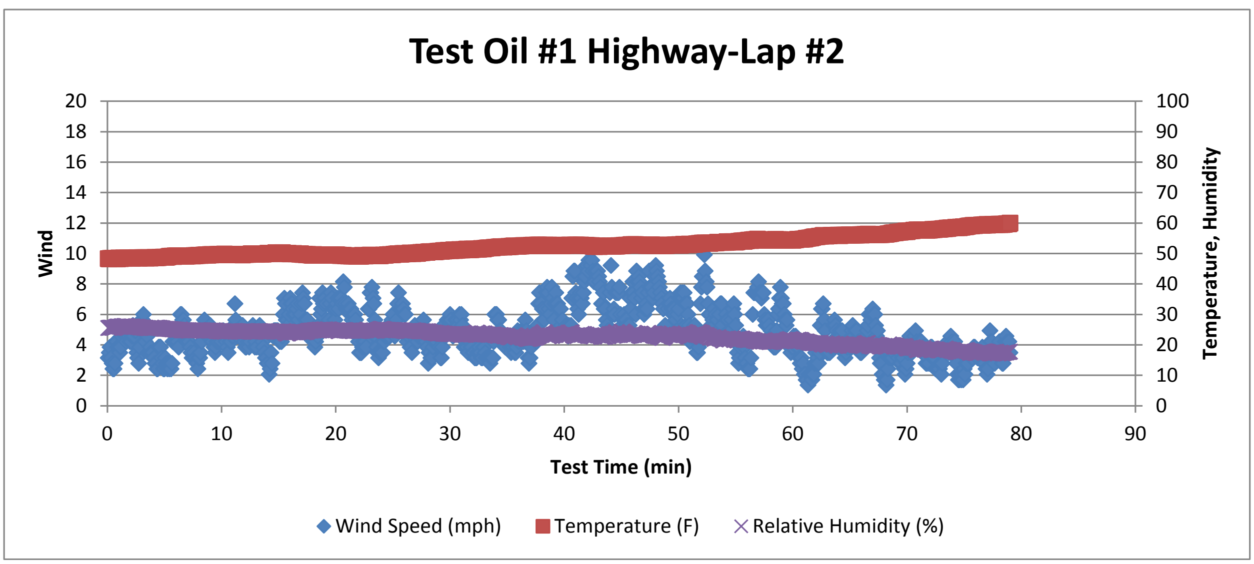
Note: The variation in wind speed is calculated from run to run.

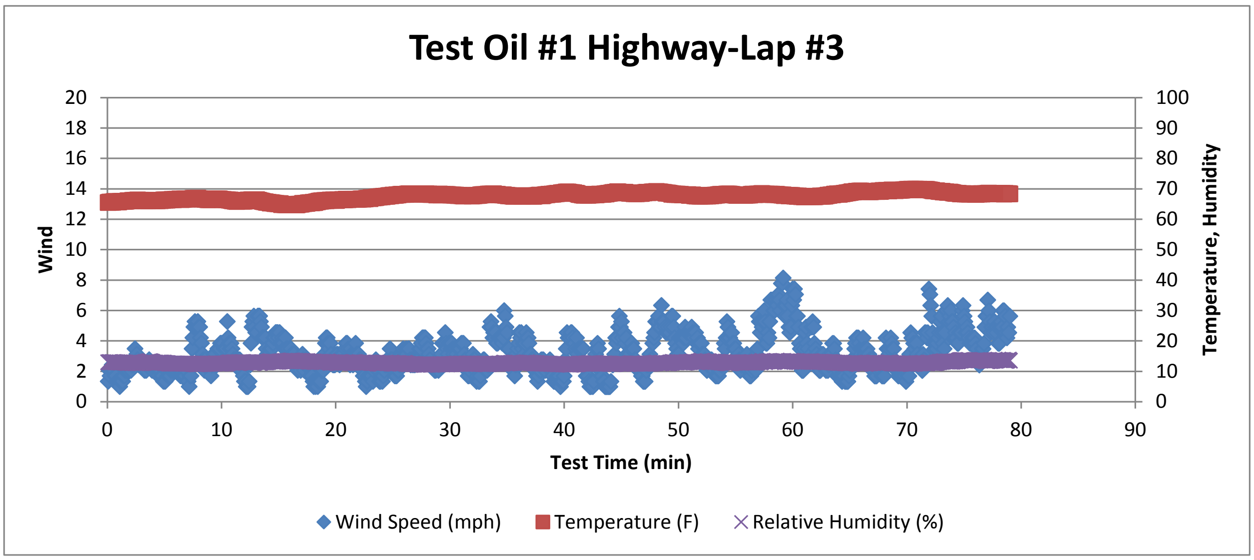

Baseline #1 Highway-Lap #1
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #1 Highway-Lap #2
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #1 Highway-Lap #3
Wind
Temperature, Humidity
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
80
90
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #1 Highway-Lap #1
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #1 Highway-Lap #2
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #1 Highway-Lap #3
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

Test #2 City Weather Data Summary
Baseline #1 City Segment and Test Oil #1 City Segment

Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	9.92	3.13	*22.07	---	80.50	84.50	4.00	9.50
Run #2	*12.83	7.06	*20.29	2.91	76.80	82.60	5.80	9.28
Run #3	4.20	0.63	8.85	8.63	43.91	56.57	12.66	20.09
Segment	8.98	0.63	22.07	8.63	43.91	84.50	40.59	12.96
Constraint	**≤12 (mph)**	**na (mph)**	**≤15 (mph)**	**≤5 (mph)**	**≥40° (F)**	**≤100° (F)**	**≤30° (F)**	**na (%)**

Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	6.35	1.70	12.78	---	66.19	69.14	2.95	15.26
Run #2	6.75	2.06	12.07	0.40	68.87	70.70	1.83	14.80
Run #3	3.88	0.63	8.14	2.87	48.49	68.04	19.55	26.12
Segment	5.66	0.63	12.78	2.87	48.49	70.70	22.21	18.73
Constraint	**≤12 (mph)**	**na (mph)**	**≤15 (mph)**	**≤5 (mph)**	**≥40° (F)**	**≤100° (F)**	**≤30° (F)**	**na (%)**

Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	6.22	0.63	22.07	6.04	43.91	84.50	40.59	15.84
Constraint	**≤12 (mph)**	**na (mph)**	**≤15 (mph)**	**≤5 (mph)**	**≥40° (F)**	**≤100° (F)**	**≤30° (F)**	**na (%)**

Note: The variation in wind speed is calculated from run to run.
*Indicates weather parameters that are out of the SAE J1321 (Revision 2012-02) Recommendation

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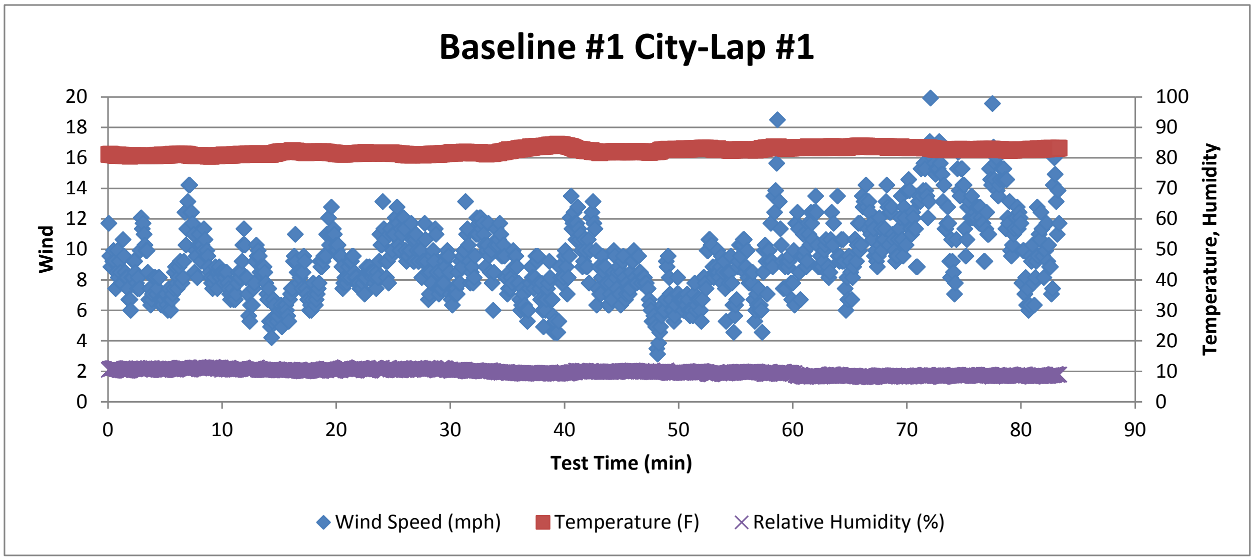
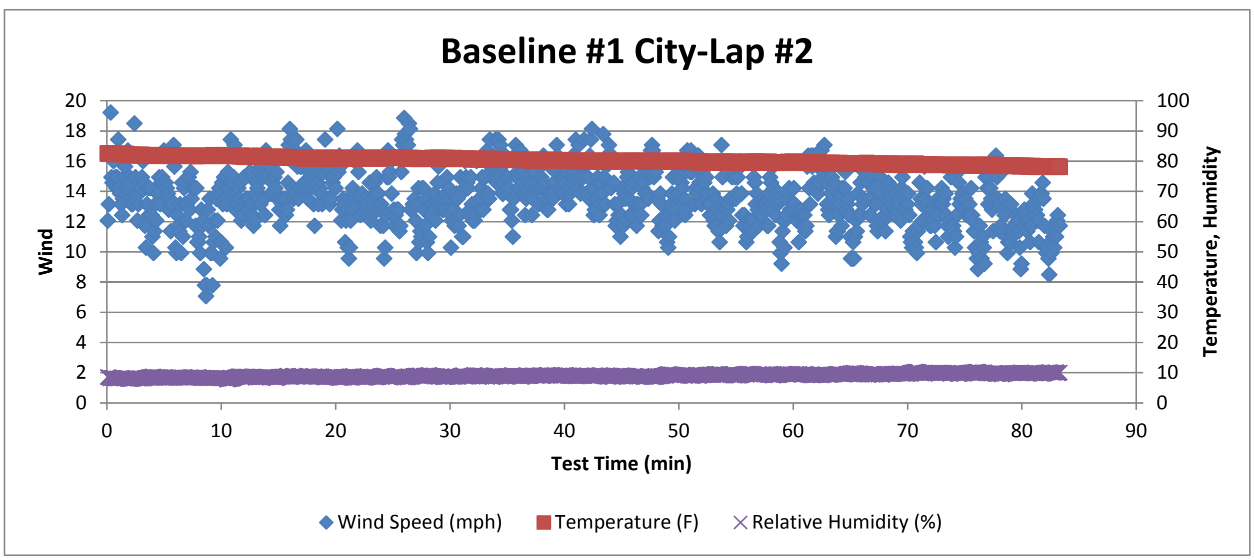
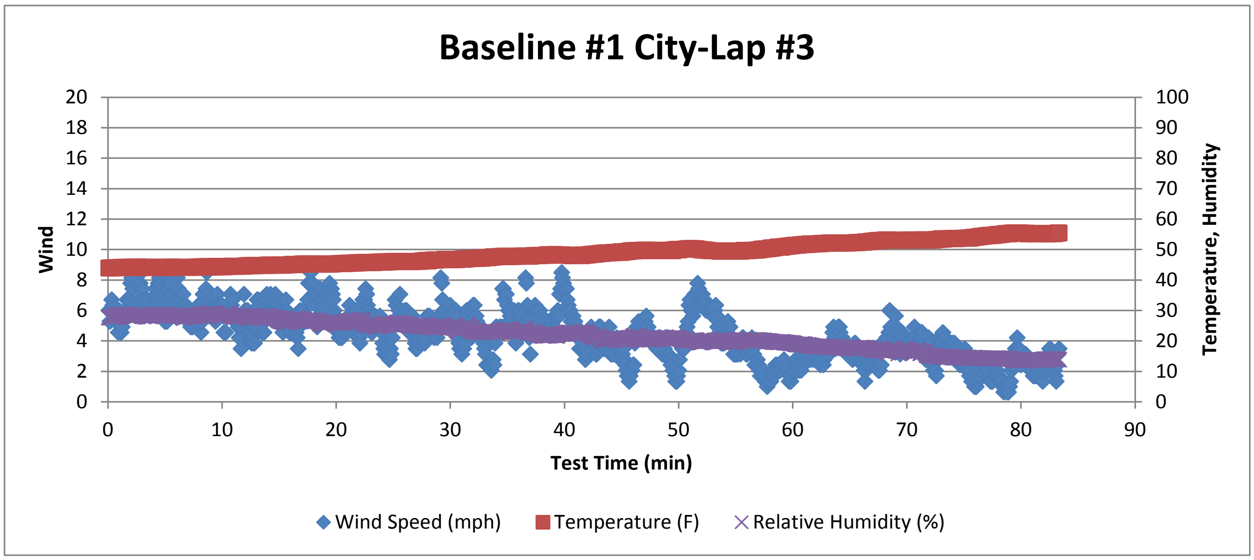
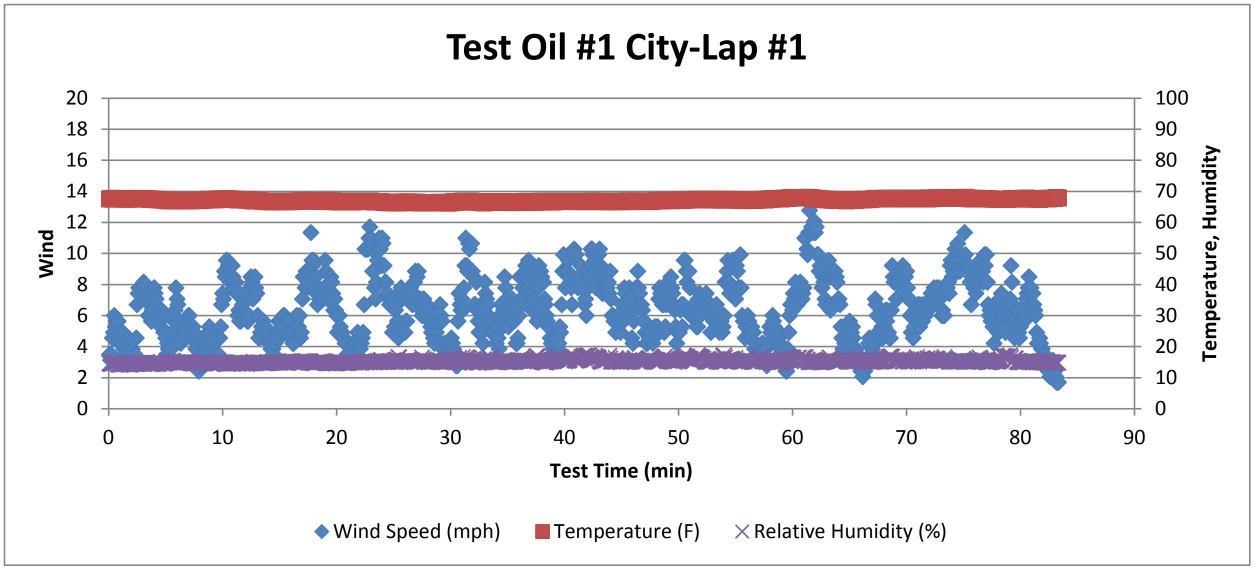
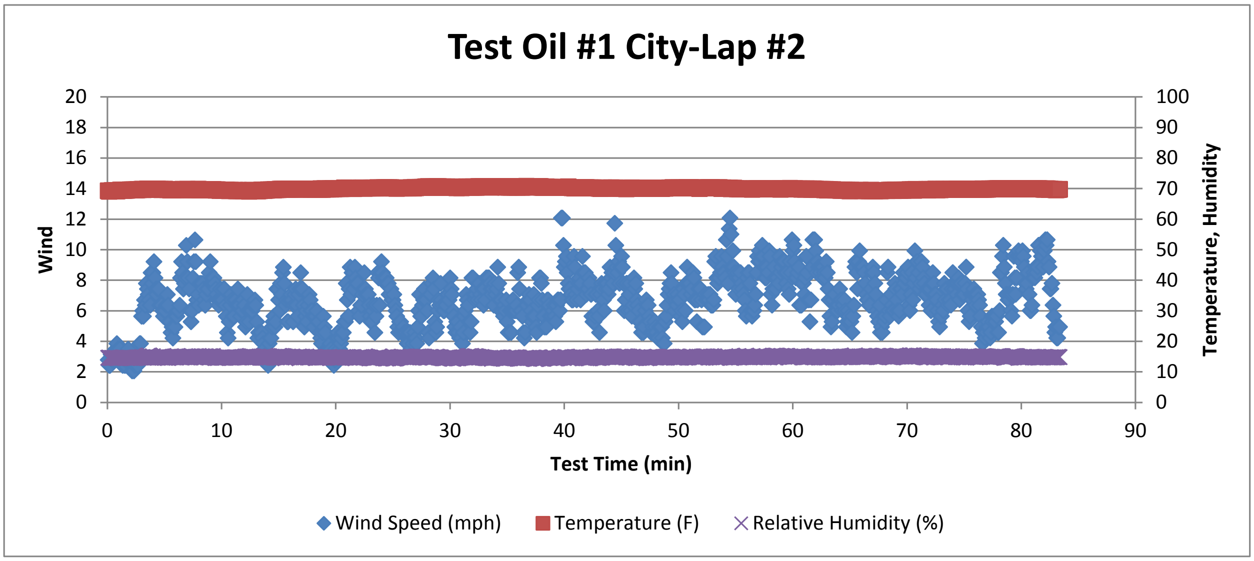
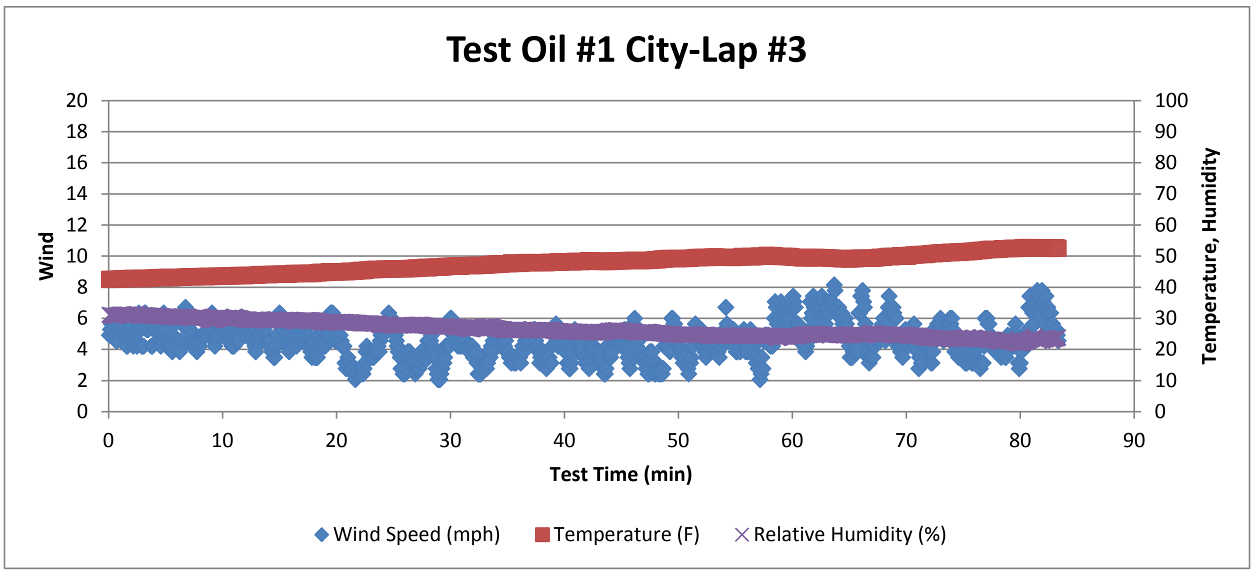

Baseline #1 City-Lap #1
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #1 City-Lap #2
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #1 City-Lap #3
Wind
Temperature, Humidity
Test Time (min)
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
80
90
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #1 City-Lap #1
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #1 City-Lap #2
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #1 City-Lap #3
Wind
Temperature, Humidity
Test Time (min)
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
80
90
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

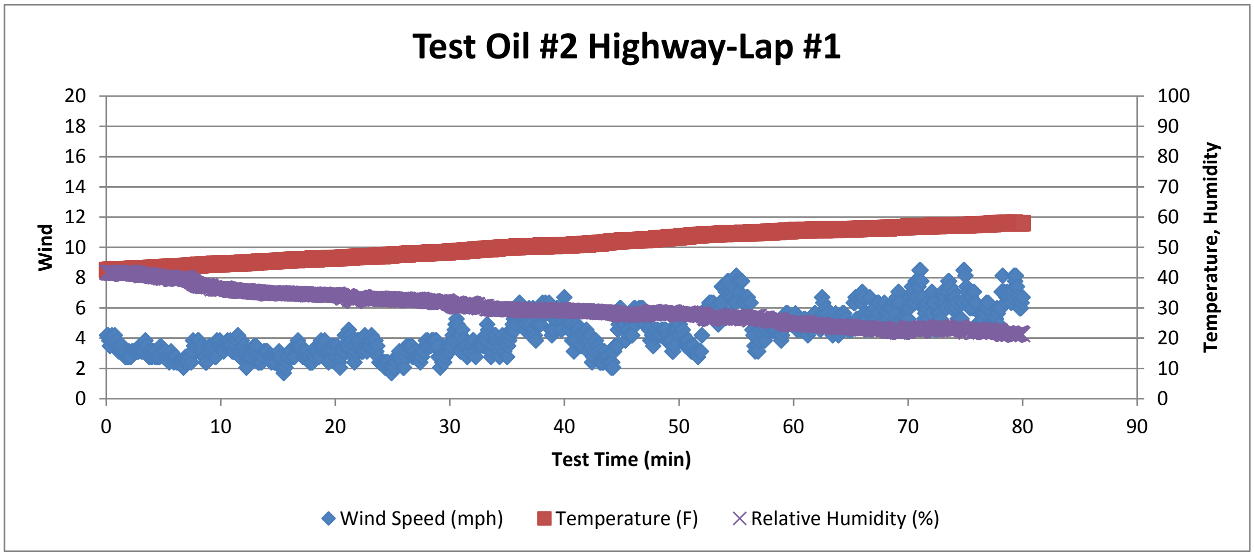
Test #3 Highway Weather Data Summary
Baseline #1 Highway Segment and Test Oil #2 Highway Segment

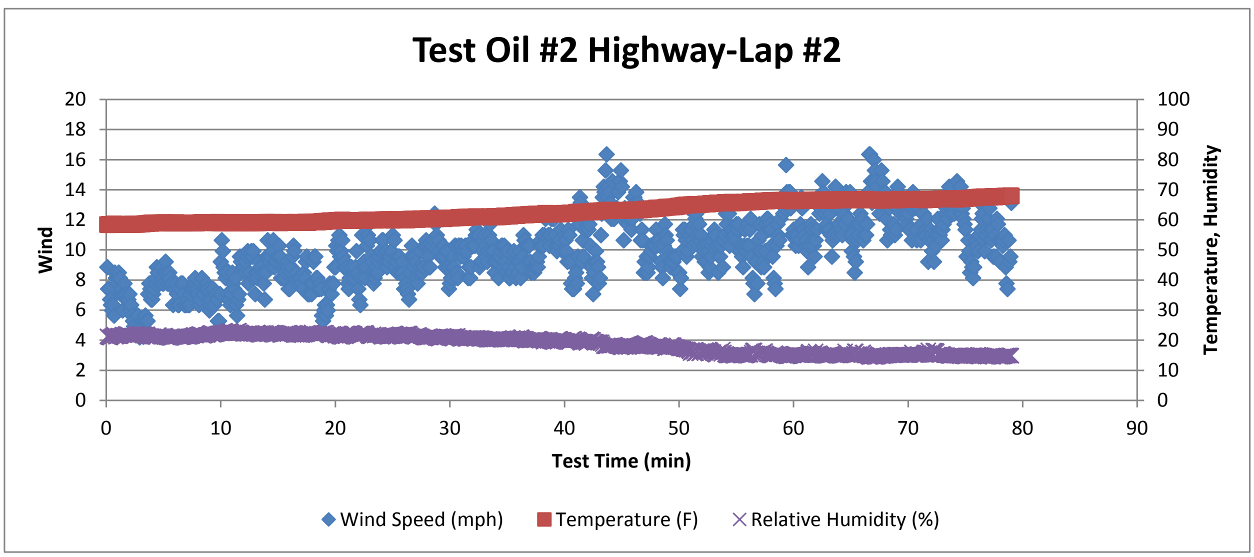
Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	6.49	1.70	10.28	---	59.09	68.01	8.92	22.70
Run #2	5.47	2.06	10.64	1.02	71.20	76.80	5.60	12.67
Run #3	5.21	0.63	8.85	1.28	52.26	65.14	12.88	35.35
Segment	5.72	0.63	10.64	1.28	52.26	76.80	24.54	23.57
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

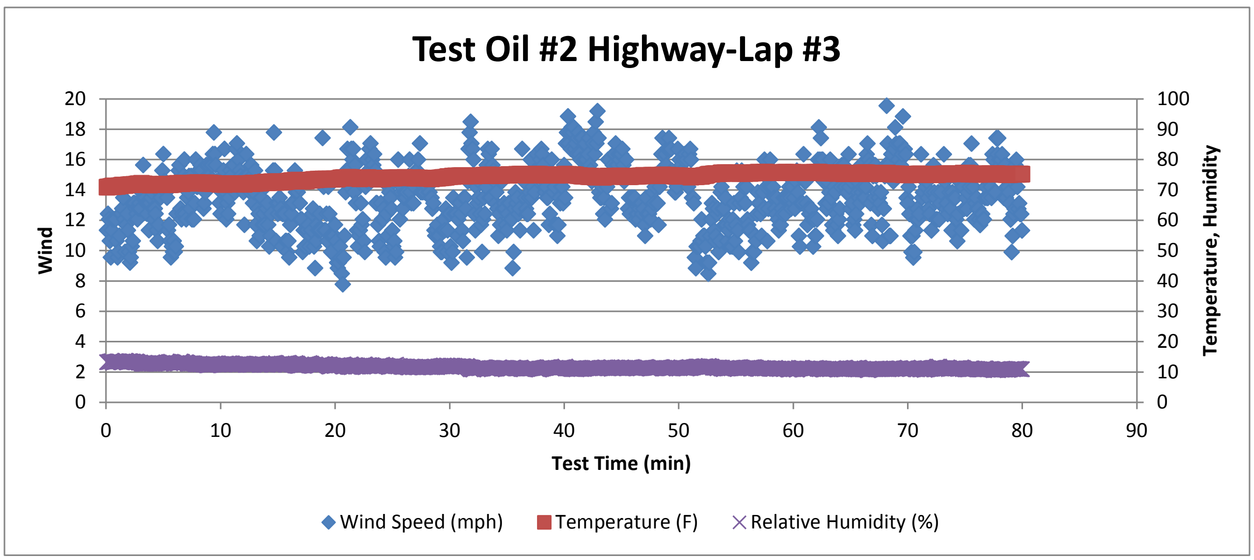
Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	4.35	1.70	8.49	---	42.47	58.22	15.75	29.85
Run #2	9.92	4.20	16.36	0.24	58.34	68.06	9.72	18.83
Run #3	13.46	7.78	19.57	1.86	70.90	75.90	5.00	11.71
Segment	9.24	1.70	19.57	9.11	42.47	75.90	33.43	20.13
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	7.48	0.63	19.57	9.11	42.47	76.80	34.33	21.85
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Note: The variation in wind speed is calculated from run to run.


Test Oil #2 Highway-Lap #1
Wind
Temperature, Humidity
Test Time (min)
0
10
20
30
40
50
60
70
80
90
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #2 Highway-Lap #2
Wind
Temperature, Humidity
Test Time (min)
0
10
20
30
40
50
60
70
80
90
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #2 Highway-Lap #3
Wind
Temperature, Humidity
Test Time (min)
0
10
20
30
40
50
60
70
80
90
2
4
6
8
10
12
14
16
18
20
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

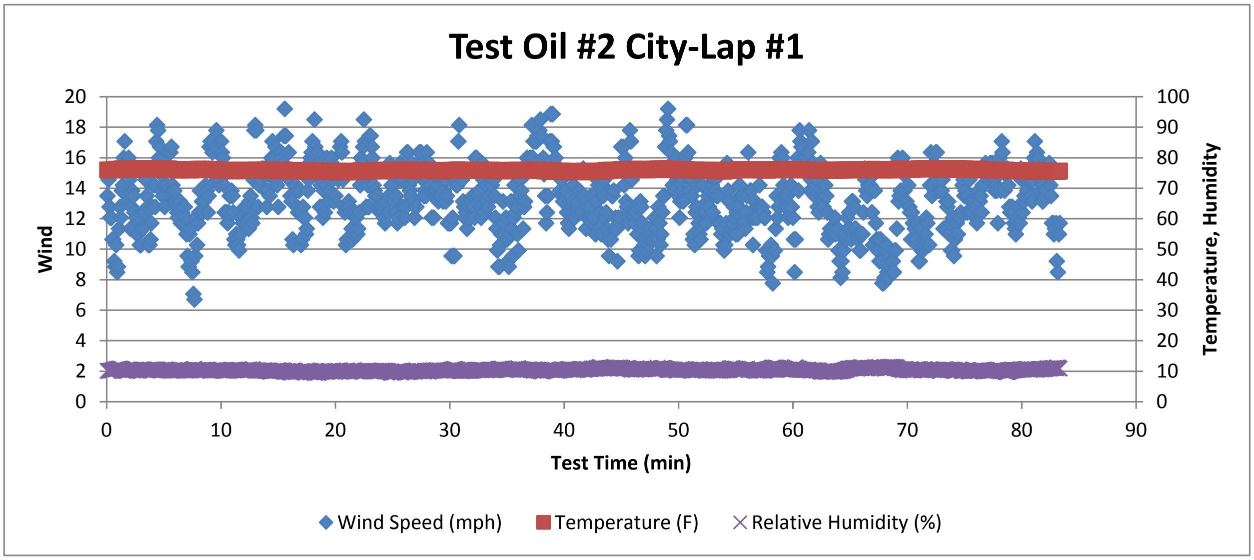
Test #4 City Weather Data Summary
Baseline #1 City Segment and Test Oil #2 City Segment

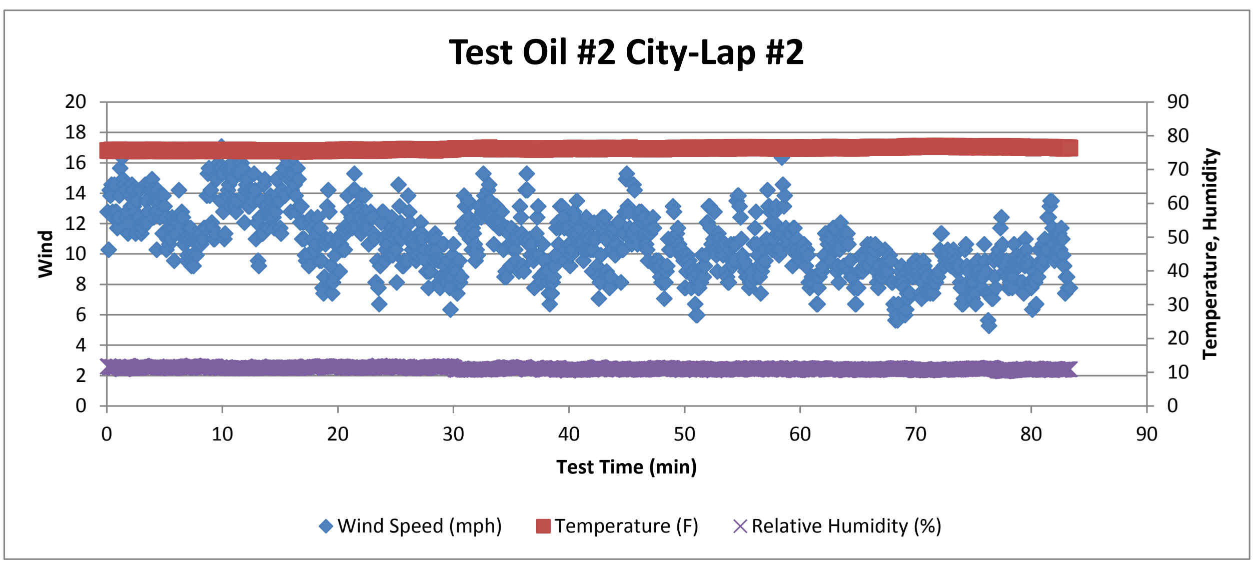
Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	9.92	3.13	*22.07	---	80.50	84.50	4.00	9.50
Run #2	*12.83	7.06	*20.29	2.91	76.80	82.60	5.80	9.28
Run #3	4.20	0.63	8.85	8.63	43.91	56.57	12.66	20.09
Segment	8.98	0.63	22.07	8.63	43.91	84.50	40.59	12.96
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

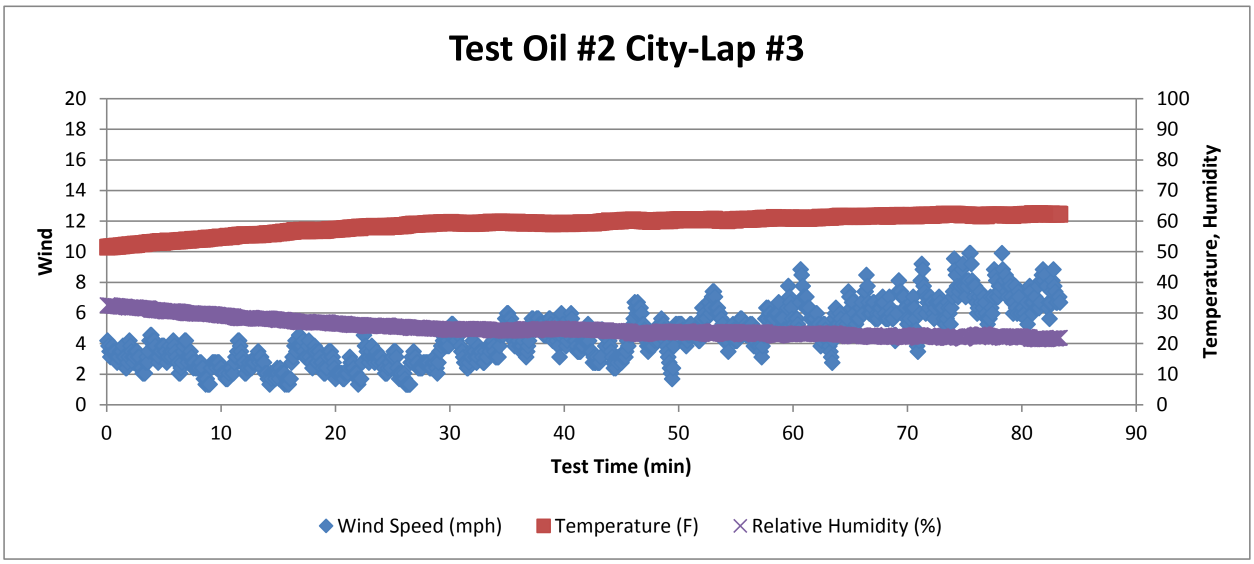
Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	13.13	6.71	20.29	---	75.30	76.50	1.20	10.61
Run #2	10.18	4.92	17.07	0.24	75.40	77.00	1.60	11.07
Run #3	5.05	1.35	9.92	1.86	51.52	64.02	12.50	24.07
Segment	5.66	0.63	12.78	8.07	48.49	70.70	22.21	18.73
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	8.50	0.63	22.07	8.92	43.91	84.50	40.59	14.10
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Note: The variation in wind speed is calculated from run to run.
*Indicates weather parameters that are out of the SAE J1321 (Revision 2012-02) Recommendation


Test Oil #2 City-Lap #1
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #2 City-Lap #2
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test Oil #2 City-Lap #3
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100

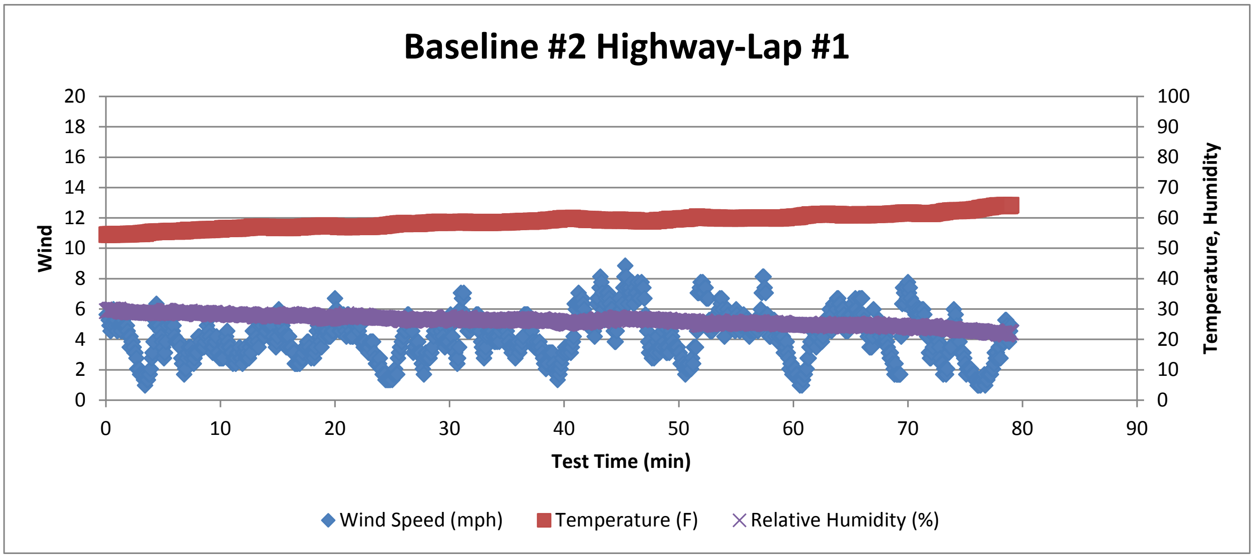
Baseline #1 Highway Segment and Baseline #2 Highway Segment

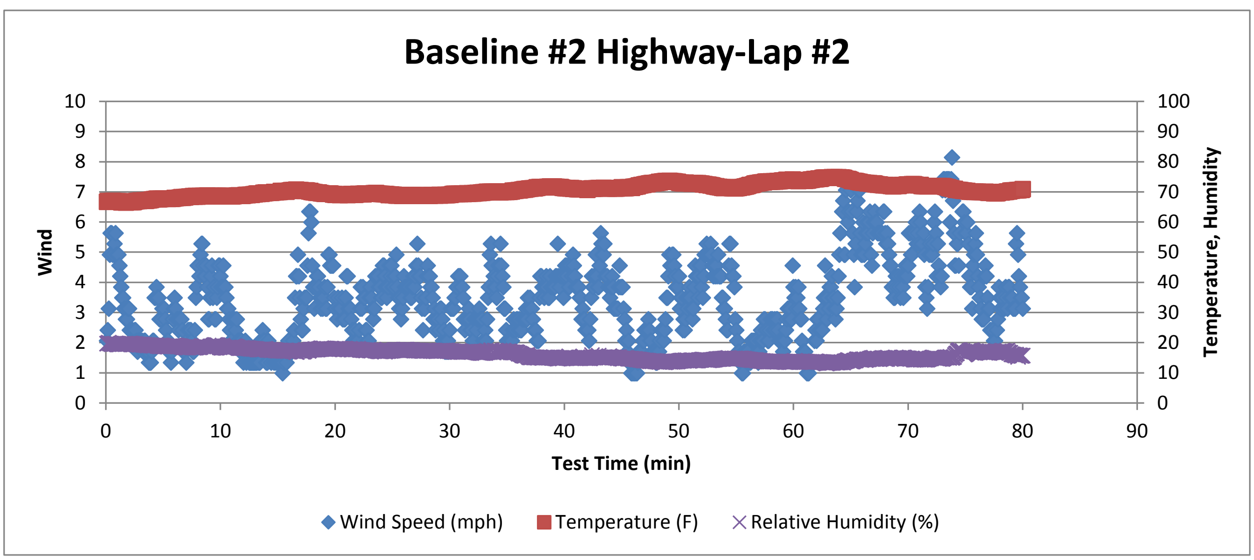
Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	6.49	1.70	10.28	---	59.09	68.01	8.92	22.70
Run #2	5.47	2.06	10.64	1.02	71.20	76.80	5.60	12.67
Run #3	5.21	0.63	8.85	1.28	52.26	65.14	12.88	35.35
Segment	5.72	0.63	10.64	1.28	52.26	76.80	24.54	23.57
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

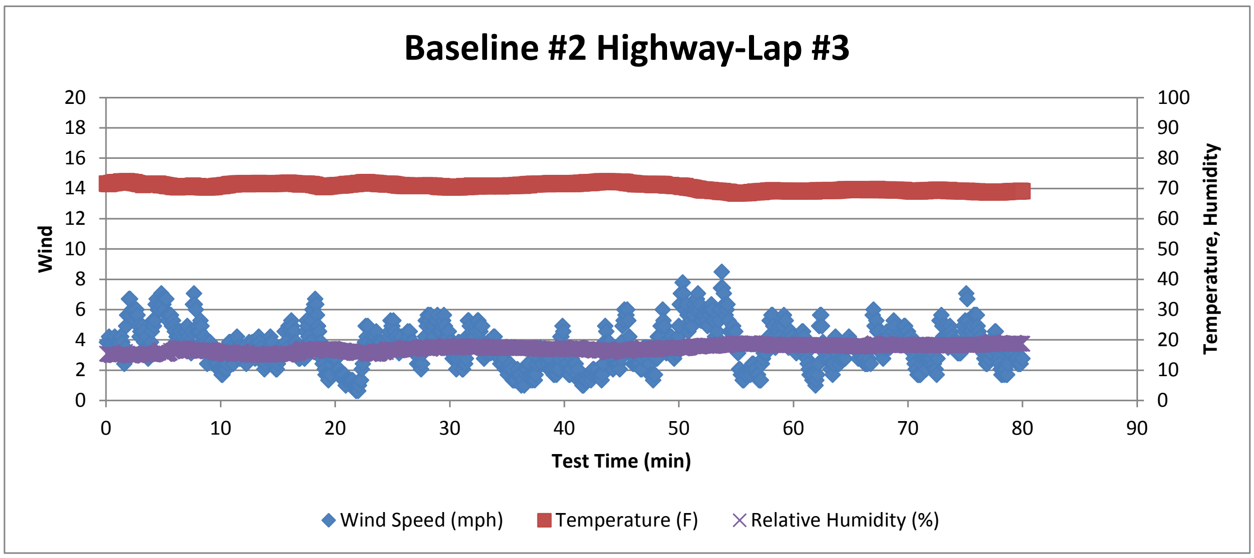
Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	4.16	0.99	8.85	---	54.47	64.22	9.75	26.26
Run #2	3.44	0.99	8.14	0.24	66.47	74.90	8.43	16.20
Run #3	3.56	0.63	8.49	1.86	68.37	72.40	4.03	17.19
Segment	3.72	0.63	8.85	0.72	54.47	74.90	20.43	19.88
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	4.72	0.63	10.64	3.04	52.26	76.80	24.54	21.73
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Note: The variation in wind speed is calculated from run to run.


Baseline #2 Highway-Lap #1
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #2 Highway-Lap #2
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #2 Highway-Lap #3
Wind
Temperature, Humidity
Test Time (min)
20
18
16
14
12
10
8
6
4
2
0
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

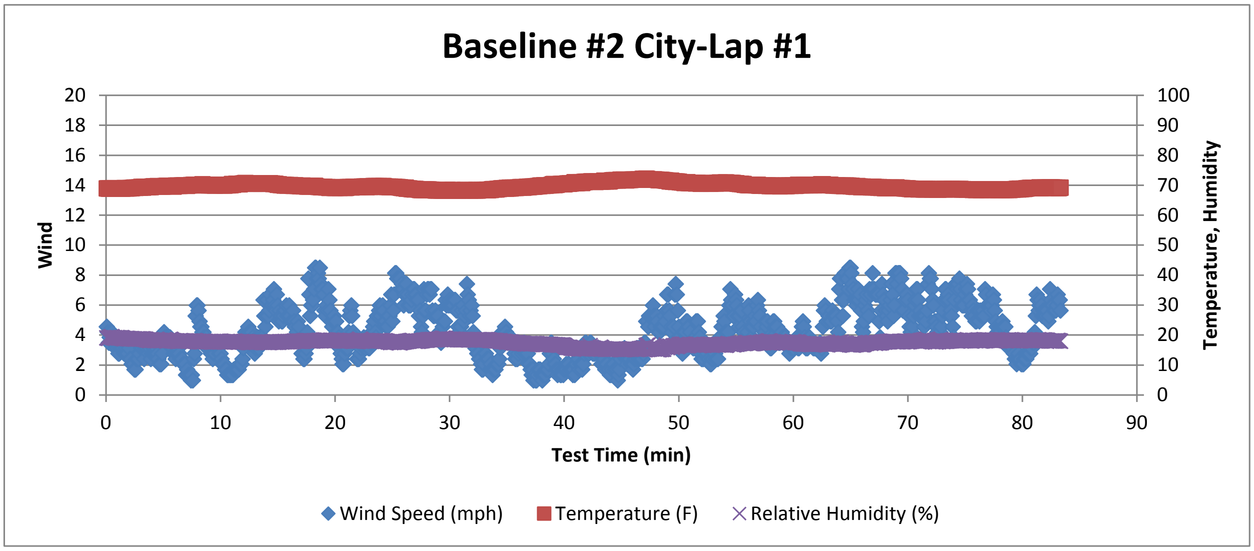
Baseline #1 City Segment and Baseline #2 City Segment

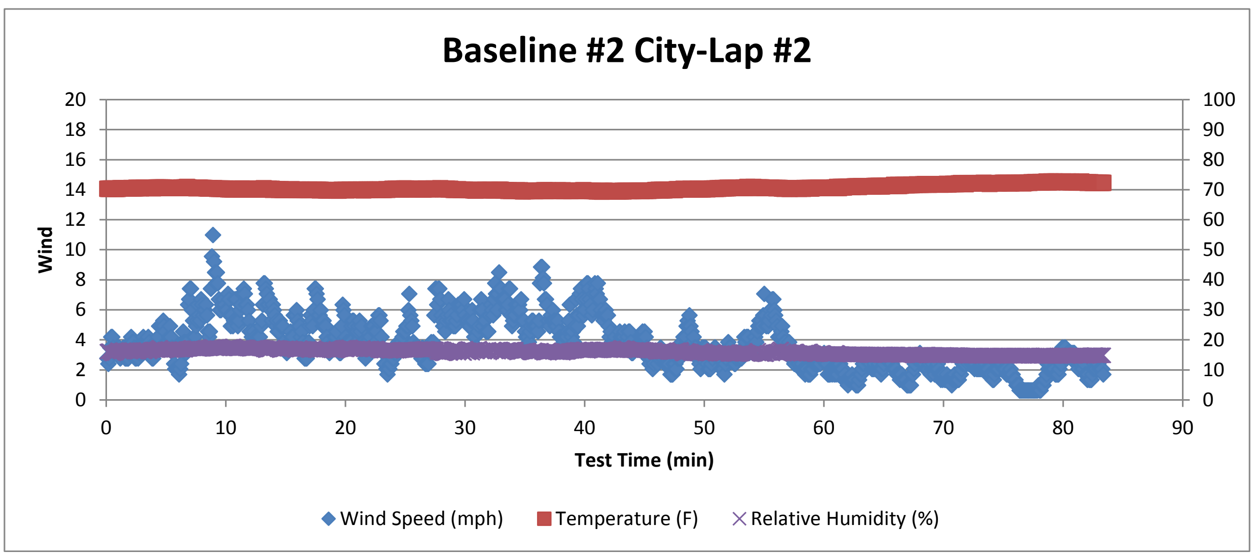
Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	9.92	3.13	*22.07	---	80.50	84.50	4.00	9.50
Run #2	*12.83	7.06	*20.29	2.91	76.80	82.60	5.80	9.28
Run #3	4.20	0.63	8.85	8.63	43.91	56.57	12.66	20.09
Segment	8.98	0.63	22.07	8.63	43.91	84.50	40.59	12.96
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

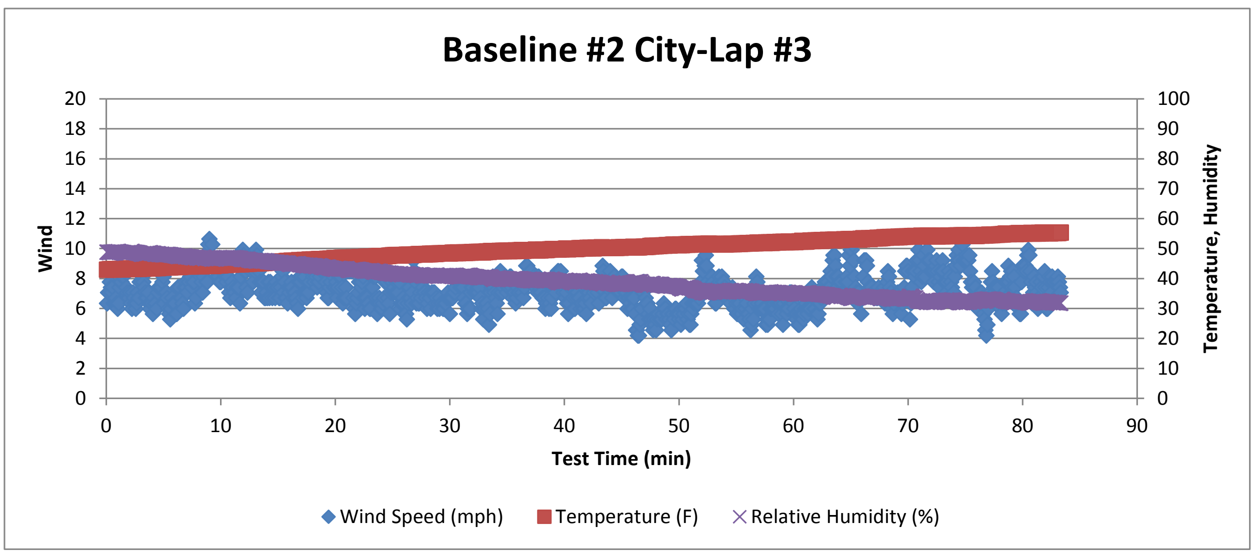
Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	4.42	0.99	9.92	---	68.21	72.20	3.99	17.59
Run #2	3.45	0.63	10.99	0.40	69.40	72.70	3.30	15.91
Run #3	7.53	4.20	12.78	2.87	43.00	58.31	15.31	37.37
Segment	5.66	0.63	12.78	2.87	48.49	70.70	22.21	18.73
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	5.90	0.63	22.07	6.47	43.91	84.50	40.59	12.96
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Note: The variation in wind speed is calculated from run to run.


Baseline #2 City-Lap #1
Wind
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100


Baseline #2 City-Lap #2
Wind
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100


Baseline #2 City-Lap #3
Wind
Temperature, Humidity
20
18
16
14
12
10
8
6
4
2
0
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

Appendix B
T/C Ratios & Lap Times

Baseline #1 Highway Segment and Test Oil #1 Highway Segement

Baseline #1 Highway Lap Times (Target Time: 1:18:36)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:18:36.2	1:18:36.4	0.004%	Truck 01	Truck 02
Run #2	1:18:36.3	1:18:36.2		0.002%	-0.004%
Run #3	1:18:35.7	1:18:37.4		-0.011%	0.021%

Test Oil #1 Highway Lap Times (Target Time: 1:18:36)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:18:36.3	1:18:36.7	0.002%	0.006%
Run #2	1:18:36.3	1:18:36.6	0.002%	0.004%
Run #3	1:18:36.3	1:18:37.1	0.002%	0.015%

Baseline #1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	27.45	27.55	1.0036	
Run #2	27.45	27.40	0.9982	0.544%
Run #3	27.65	27.50	0.9946	0.904%

Test Oil #1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	29.85	29.55	0.9899	
Run #2	28.45	28.25	0.9930	-0.305%
Run #3	27.95	27.70	0.9911	-0.112%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	0.75%	± 0.77%
Improvement	0.75%	± 0.78%

Baseline #1 City Segment and Test Oil #1 City Segement

Baseline #1 City Lap Times (Target Time: 1:45:43)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:45:43.5	1:45:44.2	0.011%	Truck 01	Truck 02
Run #2	1:45:43.3	1:45:43.6		-0.003%	-0.009%
Run #3	1:45:43.2	1:45:38.0		-0.005%	-0.098%
Test #1 Oil City Lap Times (Target Time: 1:45:43)					
	Lap Time		Repeat ± 0.25%		
	Truck 01	Truck 02	Truck 01	Truck 02	
Run #1	1:45:43.3	1:45:43.3	-0.003%	-0.014%	
Run #2	1:45:43.2	1:45:43.4	-0.005%	-0.013%	
Run #3	1:45:43.1	1:45:43.8	-0.006%	-0.006%	

Baseline #1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	29.50	29.25	0.9915	
Run #2	29.65	29.70	1.0017	-1.025%
Run #3	31.25	30.95	0.9904	0.114%
Test Oil #1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	29.80	29.10	0.9765	
Run #2	29.75	29.10	0.9782	-0.168%
Run #3	30.95	30.10	0.9725	0.407%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	1.89%	± 1.10%
Improvement	1.93%	± 1.13%

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Baseline #1 Highway Segment and Test Oil #2 Highway Segement

Baseline #1 Highway Lap Times (Target Time: 1:18:36)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:18:36.2	1:18:36.4	0.004%	Truck 01	Truck 02
Run #2	1:18:36.3	1:18:36.2		0.002%	-0.004%
Run #3	1:18:35.7	1:18:37.4		-0.011%	0.021%

Test Oil #2 Highway Lap Times (Target Time: 1:18:36)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:18:35.4	1:18:35.3	-0.017%	-0.023%
Run #2	1:18:36.4	1:18:36.8	0.004%	0.008%
Run #3	1:18:36.3	1:18:36.7	0.002%	0.006%

Baseline #1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	27.45	27.55	1.0036	
Run #2	27.45	27.40	0.9982	0.544%
Run #3	27.65	27.50	0.9946	0.904%

Test Oil #2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	28.90	28.40	0.9827	
Run #2	28.35	27.90	0.9841	-0.145%
Run #3	27.80	27.45	0.9874	-0.479%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	1.41%	± 0.83%
Improvement	1.43%	± 0.84%

Baseline #1 City Segment and Test Oil #2 City Segement

Baseline #1 City Lap Times (Target Time: 1:45:43)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:45:43.5	1:45:44.2	0.011%	Truck 01	Truck 02
Run #2	1:45:43.3	1:45:43.6		-0.003%	-0.009%
Run #3	1:45:43.2	1:45:38.0		-0.005%	-0.098%

Test Oil #2 City Lap Times (Target Time: 1:45:43)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:45:43.3	1:45:43.3	-0.046%	0.000%
Run #2	1:45:43.2	1:45:43.4	-0.061%	0.000%
Run #3	1:45:43.1	1:45:43.8	-0.092%	0.000%

Baseline #1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	29.50	29.25	0.9915	
Run #2	29.65	29.70	1.0017	-1.025%
Run #3	31.25	30.95	0.9904	0.114%

Test Oil #2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	30.20	29.30	0.9702	
Run #2	29.85	29.05	0.9732	-0.309%
Run #3	30.75	30.00	0.9756	-0.558%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	2.17%	± 1.09%
Improvement	2.21%	± 1.12%

Baseline #2 Highway Segment and Test Oil #1 Highway Segement

Baseline #2 Highway Lap Times (Target Time: 1:18:36)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:18:36.0	1:18:36.6	0.004%	Truck 01	Truck 02
Run #2	1:18:36.3	1:18:36.7		0.002%	-0.004%
Run #3	1:18:36.4	1:18:36.7		-0.011%	0.021%

Test Oil #1 Highway Lap Times (Target Time: 1:18:36)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:18:36.3	1:18:36.7	0.002%	0.006%
Run #2	1:18:36.3	1:18:36.6	0.002%	0.004%
Run #3	1:18:36.3	1:18:37.1	0.002%	0.015%

Baseline #2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	28.10	28.10	1.0000	
Run #2	27.35	27.60	1.0091	-0.914%
Run #3	27.65	27.75	1.0036	-0.362%

Test Oil #1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	29.85	29.55	0.9899	
Run #2	28.45	28.25	0.9930	-0.305%
Run #3	27.95	27.70	0.9911	-0.112%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	1.29%	± 0.77%
Improvement	1.30%	± 0.78%

Baseline #2 Highway Segment and Test Oil #2 Highway Segement

Baseline # 2 Highway Lap Times (Target Time: 1:18:36)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:18:36.0	1:18:36.6	0.004%	Truck 01	Truck 02
Run #2	1:18:36.3	1:18:36.7		0.002%	-0.004%
Run #3	1:18:36.4	1:18:36.7		-0.011%	0.021%

Test Oil #2 Highway Lap Times (Target Time: 1:18:36)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:18:35.4	1:18:35.3	-0.017%	-0.023%
Run #2	1:18:36.4	1:18:36.8	0.004%	0.008%
Run #3	1:18:36.3	1:18:36.7	0.002%	0.006%

Baseline #2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	28.10	28.10	1.0000	
Run #2	27.35	27.60	1.0091	-0.914%
Run #3	27.65	27.75	1.0036	-0.362%

Test # 2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	28.90	28.40	0.9827	
Run #2	28.35	27.90	0.9841	-0.145%
Run #3	27.80	27.45	0.9874	-0.479%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	1.41%	± 0.83%
Improvement	1.43%	± 0.84%

Baseline #2 City Segment and Test Oil #1 City Segement

Baseline #2 City Lap Times (Target Time: 1:45:43)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:45:43.5	1:45:44.2	0.011%	Truck 01	Truck 02
Run #2	1:45:43.3	1:45:43.6		-0.003%	-0.009%
Run #3	1:45:43.2	1:45:38.0		-0.005%	-0.098%

Test Oil #1 City Lap Times (Target Time: 1:45:43)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:45:43.3	1:45:43.3	-0.003%	-0.014%
Run #2	1:45:43.2	1:45:43.4	-0.005%	-0.013%
Run #3	1:45:43.1	1:45:43.8	-0.006%	-0.006%

Baseline #2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	29.25	29.85	1.0205	
Run #2	30.20	30.65	1.0149	0.550%
Run #3	30.45	30.95	1.0164	0.401%

Test Oil #1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	29.80	29.10	0.9765	
Run #2	29.75	29.10	0.9782	-0.168%
Run #3	30.95	30.10	0.9725	0.407%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	4.08%	± 0.65%
Improvement	4.26%	± 0.67%

Baseline #2 City Segment and Test Oil #2 City Segement

Baseline # 1 City Lap Times (Target Time: 1:45:43)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:45:43.5	1:45:44.2	0.011%	Truck 01	Truck 02
Run #2	1:45:43.3	1:45:43.6		-0.003%	-0.009%
Run #3	1:45:43.2	1:45:38.0		-0.005%	-0.098%

Test # 2 City Lap Times (Target Time: 1:45:43)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:45:43.3	1:45:43.3	-0.046%	0.000%
Run #2	1:45:43.2	1:45:43.4	-0.061%	0.000%
Run #3	1:45:43.1	1:45:43.8	-0.092%	0.000%

Baseline # 2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	29.25	29.85	1.0205	
Run #2	30.20	30.65	1.0149	0.550%
Run #3	30.45	30.95	1.0164	0.401%

Test # 2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	30.20	29.30	0.9702	
Run #2	29.85	29.05	0.9732	-0.309%
Run #3	30.75	30.00	0.9756	-0.558%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	2.17%	± 1.09%
Improvement	2.21%	± 1.12%

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Baseline #1 Highway Segment and Baseline #2 Highway Segement

Baseline #1 Highway Lap Times (Target Time: 1:18:36)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:18:36.2	1:18:36.4	0.004%	Truck 01	Truck 02
Run #2	1:18:36.3	1:18:36.2		0.002%	-0.004%
Run #3	1:18:35.7	1:18:37.4		-0.011%	0.021%

Baseline #2 Highway Lap Times (Target Time: 1:18:36)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:18:36	1:18:37	0.000%	0.000%
Run #2	1:18:36	1:18:37	0.006%	0.002%
Run #3	1:18:36	1:18:37	0.008%	0.002%

Baseline #1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	27.45	27.55	1.0036	
Run #2	27.45	27.40	0.9982	0.544%
Run #3	27.65	27.50	0.9946	0.904%

Baseline#2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	28.10	28.10	1.0000	
Run #2	27.35	27.60	1.0091	-0.914%
Run #3	27.65	27.75	1.0036	-0.362%

Change in Highway Baseline		
	Nominal	Confidence Interval
Fuel Saved	-0.55%	± 1.04%
Improvement	-0.54%	± 1.03%

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Baseline #1 City Segment and Baseline #2 City Segement

Baseline #1 City Lap Times (Target Time: 1:48:30)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:48:36	1:48:32	0.061%	Truck 01	Truck 02
Run #2	1:48:30	1:48:30		-0.092%	-0.031%
Run #3	1:48:31	1:48:31		-0.077%	-0.015%

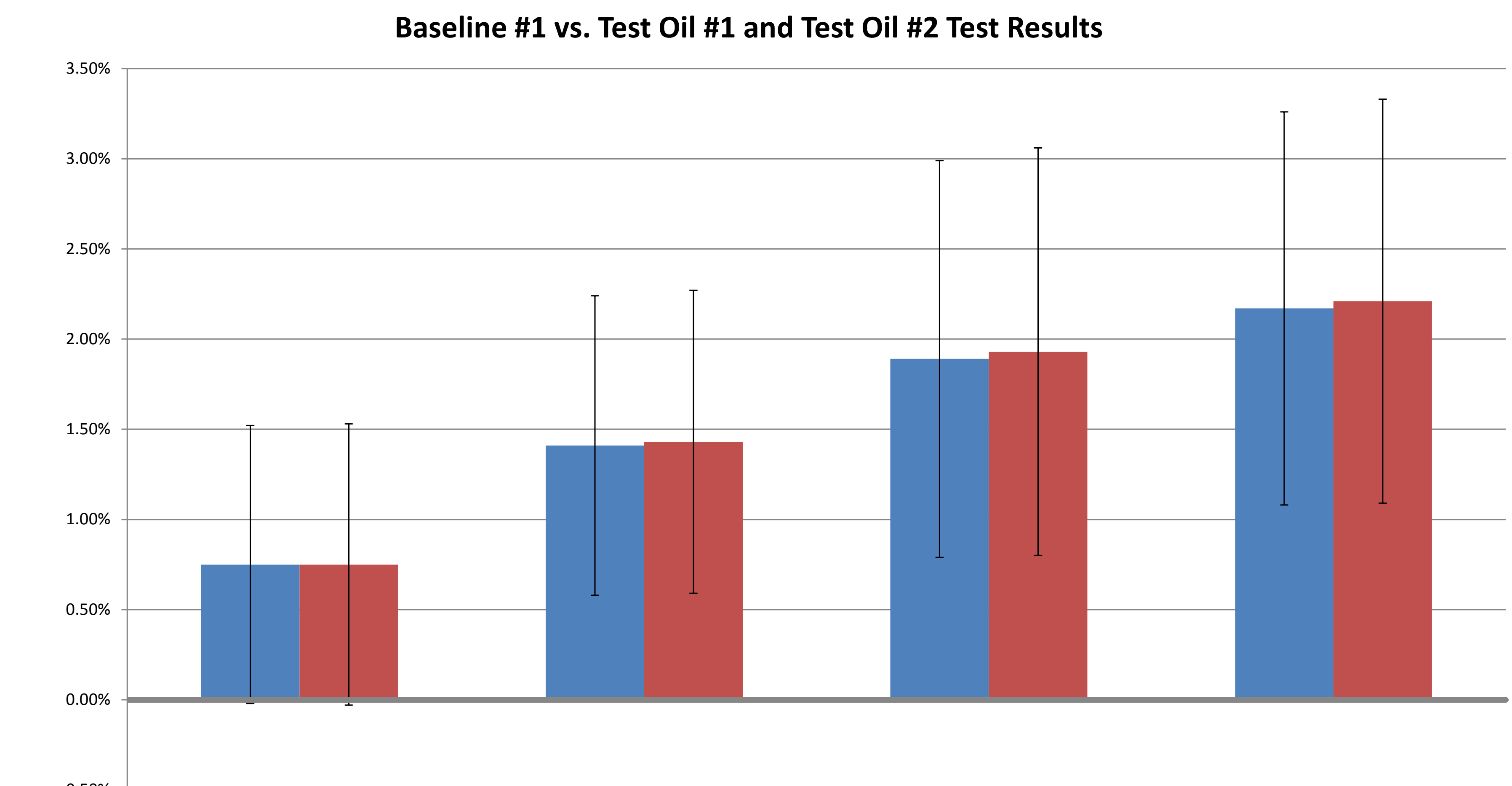
Baseline #2 City Lap Times (Target Time: 1:48:30)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:48:30	1:48:31	-0.092%	-0.015%
Run #2	1:48:33	1:48:31	-0.046%	-0.015%
Run #3	1:48:30	1:48:32	-0.092%	0.000%

Baseline #1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	27.45	27.55	1.0036	
Run #2	27.45	27.40	0.9982	0.544%
Run #3	27.65	27.50	0.9946	0.904%

Baseline #2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	29.25	29.85	1.0205	
Run #2	30.20	30.65	1.0149	0.550%
Run #3	30.45	30.95	1.0164	0.401%

Change in City Baseline		
	Nominal	Confidence Interval
Fuel Saved	-2.29%	± 1.11%
Improvement	-2.24%	± 1.08%

Appendix C
Test Result Graph



	Test Oil #1 Highway	Test Oil #2 Highway	Test Oil #1 City	Test Oil #2 City
Fuel Saved	0.75% ± 0.77%	1.41% ± 0.83%	1.89% ± 1.10%	2.17% ± 1.09%
Improvement	0.75% ± 0.78%	1.43% ± 0.84%	1.93% ± 1.13%	2.21% ± 1.12%

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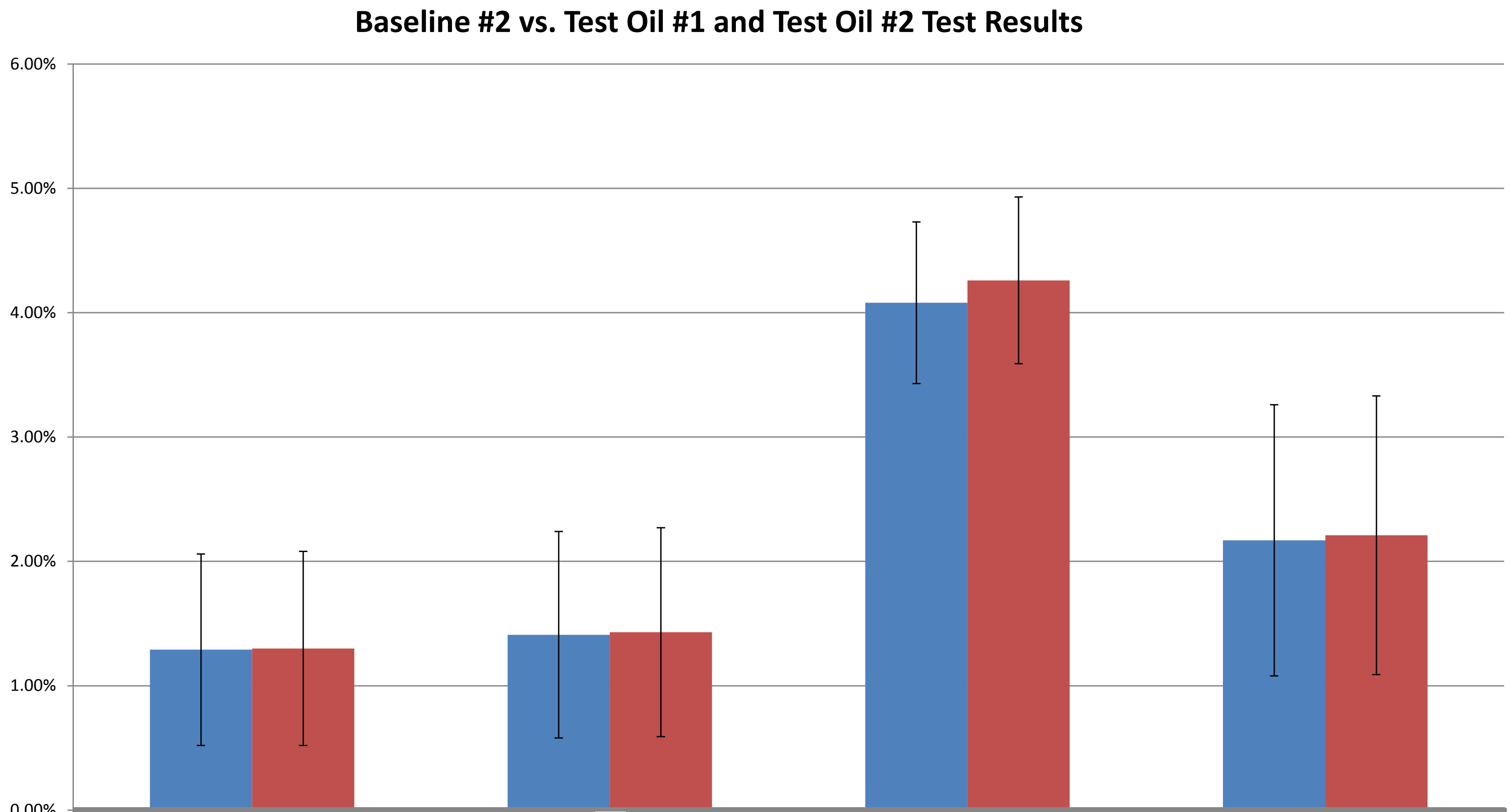
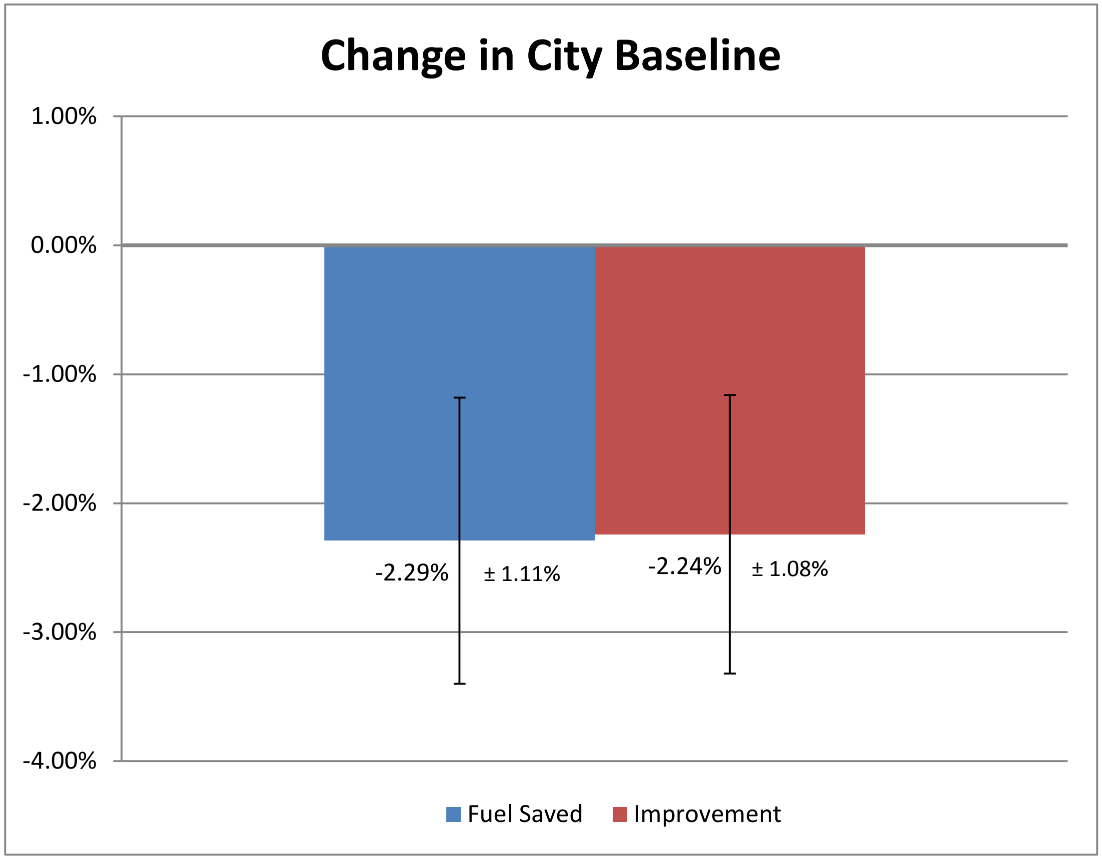


	Test Oil #1 Highway	Test Oil #2 Highway	Test Oil #1 City	Test Oil #2 City
Fuel Saved	1.29% ± 0.77%	1.41% ± 0.83%	4.08% ± 1.10%	2.17% ± 1.09%
Improvement	1.30% ± 0.78%	1.43% ± 0.84%	4.26% ± 1.13%	2.21% ± 1.12%


Change in City Baseline
1.00%
0.00%
-1.00%
-2.00%
-3.00%
-4.00%
-2.29%
± 1.11%
-2.24%
± 1.08%
Fuel Saved
Improvement

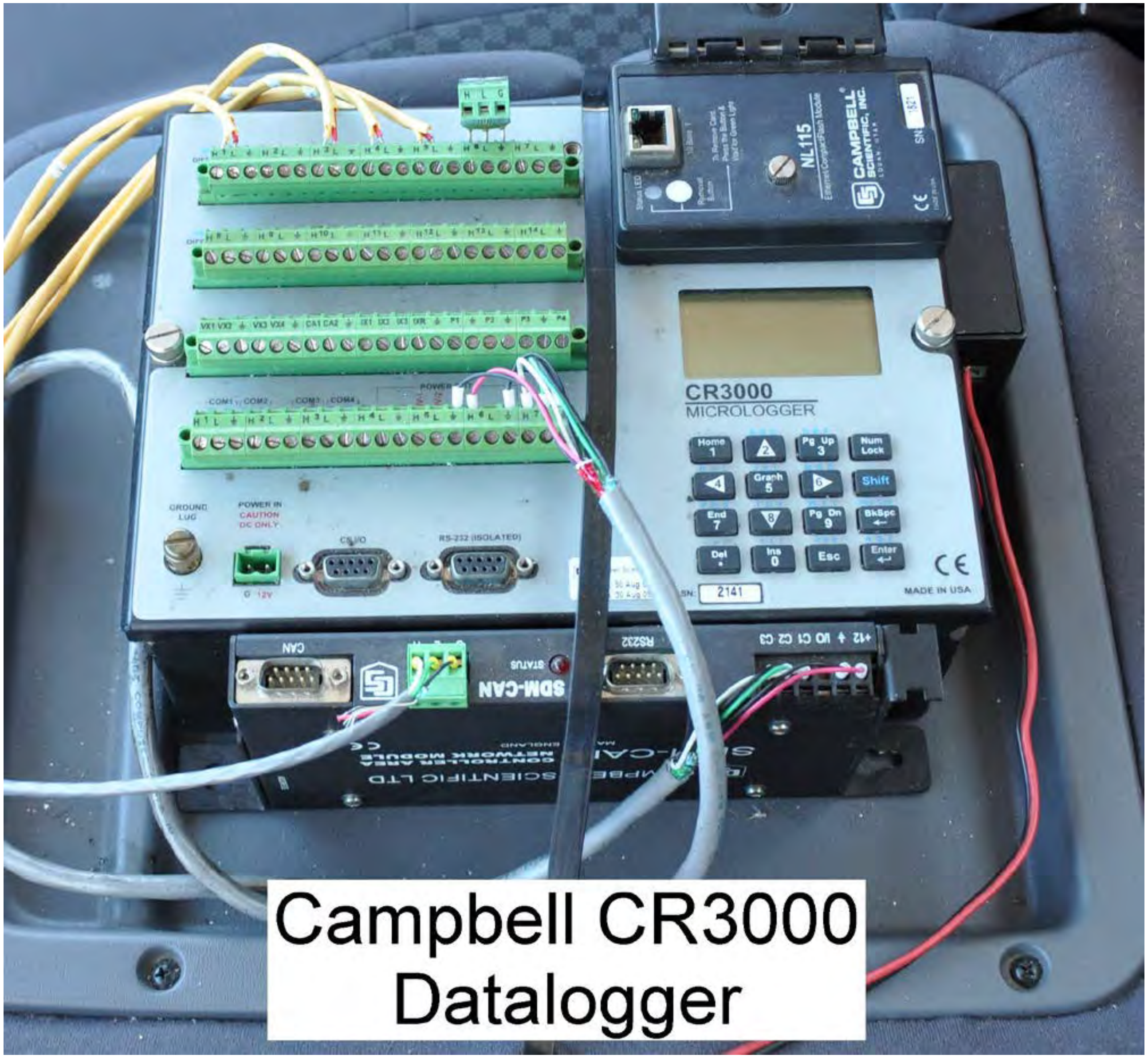
Appendix D
Photos

AM General High Mobility
Multipurpose Wheeled Vehicle
(HMMWV)

Weigh Tank and Bracket

Wheel Alignment


Portable Weather
Station


Campbell CR3000
Datalogger
CR3000
MICROLOGGER
NL115
CAMPBELL SCIENTIFIC, INC.
SDM-CAN
MADE IN USA

Weigh Tank Scale

APPENDIX B. HTV Test Report

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FUELS AND LUBRICANTS RESEARCH DIVISION
Fuels and Driveline Lubricants Research Department

Report On:

"SAE J1321 Fuel Consumption Test Program on Oshkosh M1070 Vehicles"

Conducted For:

The US Army

Oshkosh M1070 Heavy Equipment Transport (HET)
Baseline Oil: LO272251/LO310413
Test Oil 1: LO310412
Test Oil 2: LO278907/LO310410

July 14, 2015

Prepared by:

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APPENDICES

I. INTRODUCTION

At the request of The US Army, Southwest Research Institute (SwRI®) conducted a fuel economy test utilizing two Oshkosh M1070 Heavy Equipment Transport (HET) trucks. The purpose of the testing was to compare the fuel economy benefits derived from using different differential lubricants.

The procedure chosen for this evaluation was a modified version of the February 2012 revision of the SAE J1321 *"Fuel Consumption Test Procedure - Type II"*. This recommended practice provided a standardized test procedure for comparing the in-service fuel consumption of a vehicle operated under two conditions. An unchanging control vehicle (Truck 01) ran in tandem with a test vehicle (Truck 02) to provide reference fuel consumption data. The fuel consumption was measured by using weigh tanks.

A baseline segment was first conducted followed by a test segment for each differential lubricant. Finally an additional baseline segment was conducted to confirm results. The HETs were operated over both a simulated "highway" and "city" route at a closed test track.

II. TEST PLAN

A. Description of Vehicles

The US Army provided the trucks used for testing during this program.

The trucks were identical HET trucks equipped with Detroit Diesel 8V92TA engines rated at 500 hp and Allison CLT 754 Automatic Transmissions. The trucks were unloaded during testing with a tractor weight of approximately 40,900 lbs.

B. Truck Preparation

Prior to commencing with testing the following preparations were made to the trucks.

1. All wheels were aligned.
2. The engine air filters and fuel filters were replaced.
3. The engine, transmission, and transfer case fluids were changed.
4. A separate weigh tank was connected to each truck's fuel system via a three-way valve to permit operation either from the vehicle's fuel supply or from the weigh tank.
5. Each truck was equipped with a Campbell CR-3000 datalogger to record GPS position and speed, all differential temperatures, engine oil sump temperature, transfer case temperature, transmission temperature, and pedal voltage. All fluid temperatures were measured by placing a thermocouple through a modified drain plug. The data was recorded at one second intervals.
6. An electronic master switch was connected to a time counter and to the datalogger. The switch was turned on at the beginning of each run and turned off at the end of each run.

7. Practice laps were conducted to establish target times at markers on each route. The target times were specific to the driver and the truck. During the testing phase, the lap time was required to be within +/-0.25% of the target time to be considered operationally valid.

C. Test Routes (Truck Driving Cycle)

Fuel consumption was measured using simulated “highway” and “city” routes on a closed test track. The “highway” route was conducted at 25 mph for 22.5 miles and 40 mph for 22.5 miles. The “city” route was a transient route adapted from the SAE J1376 Procedure. Both routes were 45 miles long which is 5 miles short of what is required by the SAE J1321 (Revision 2012-02). These routes were chosen to keep consistency with historical test data. Additionally, the weather conditions set by the SAE J1321 (Revision 2012-02) were not met on all runs. The maximum wind speed and variation in wind speeds limits were exceeded. All weather data collected is included in Appendix A.

Table 1. Highway Route Maneuvers

Step	Maneuver	Total Distance (miles)
0	Hold 25 mph	0.00-22.50
1	Accelerate to and hold 40 mph	22.50-45.00
2	Switch off weigh tank	45.00

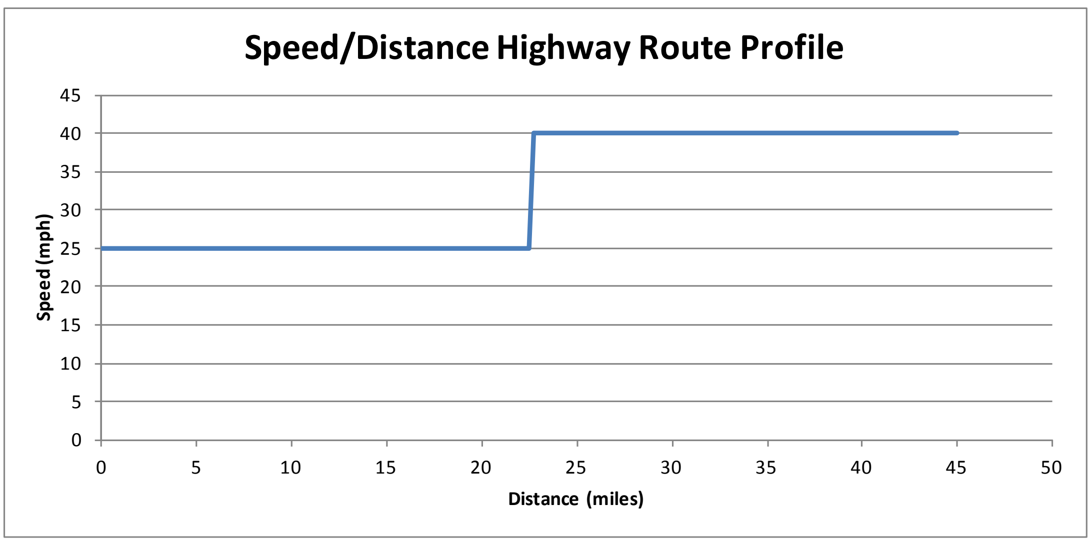


Figure 1. Highway Route Profile

Table 2. City Route Maneuvers

Step	Maneuver	Total Distance (miles)
0	Start Engine	0.00
1	30 Second Idle	0.00
2	Accelerate to and hold 5 mph	0.15
3	Accelerate to and hold 10 mph	0.48
4	Decelerate to 0mph	0.49
5	20 Second Idle	-
6	Accelerate to and hold 20 mph	0.97
7	Decelerate to 0mph	1.00
8	20 Second Idle	-
9	Accelerate to and hold 30 mph	1.44
10	Decelerate to 0mph	1.50
11	20 Second Idle	-
12	Accelerate to and hold 35 mph	1.92
13	Decelerate to 0mph	2.00
14	20 Second Idle	-
15	Accelerate to and hold 25 mph	2.56
16	Decelerate to 0mph	2.60
17	20 Second Idle	-
18	Accelerate to and hold 15 mph	2.98
19	Decelerate to 0mph	3.00
20	20 Second Idle	-
21	Repeat Steps 2-20	6.00
22	Repeat Steps 2-19	9.00
23	60 Second Idle	-
24	Accelerate to and hold 25 mph	15.00
25	Accelerate to and hold 35 mph	21.00
26	Accelerate to and hold 40 mph	27.00
27	Decelerate to and hold 25 mph	33.00
28	Accelerate to and hold 35 mph	39.00
29	Accelerate to and hold 40 mph	44.80
30	Decelerate to 0 mph	45.00
31	60 Second Idle	-
32	Shut off Engine	-

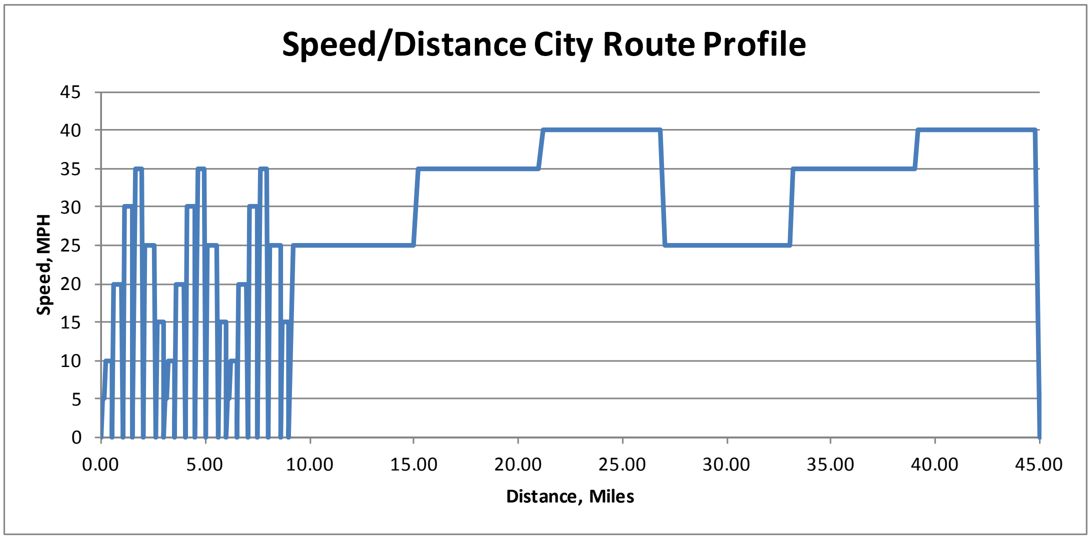


Figure 2. City Route Profile

D. Test Matrix

The test matrix consisted of eight segments, each of which constisted of three valid runs. Both trucks were operated simultaneously for each run. Baseline differential fluid (LO272251/LO310413) was used in the control truck (Truck 01) for all segments. Two test differential fluids (LO310412 & LO278907/LO310410, respectively) were evaluated in the test truck (Truck 02) for the test segments. A double flush was performed when changing differential fluids in the test truck. A single drain and fill was performed on the control truck each time the test truck fluid was changed. Each flush consisted of driving the truck for 15 minutes, draining the differential fluid from the 4 axles and 8 hubs, then adding the new differential fluid. A description of the test matrix is shown in Table 3.

Table 3. Test Matrix

Differential Fluid	Segment	Lap
Truck 01 Double Flush to LO272251/LO310413	Baseline #1 Highway Segment	Highway Lap #1
		Highway Lap #2
		Highway Lap #3
Truck 02 Double Flush to LO272251/LO310413	Baseline #1 City Segment	City Lap #1
		City Lap #2
		City Lap #3
Truck 01 Drain and fill to LO272251/LO310413	Test #1 Highway Segment	Highway Lap #1
		Highway Lap #2
		Highway Lap #3
Truck 02 Double Flush to LO310412	Test #1 City Segment	City Lap #1
		City Lap #2
		City Lap #3
Truck 01 Double Flush to LO272251/LO310413	Test #2 Highway Segment	Highway Lap #1
		Highway Lap #2
		Highway Lap #3
Truck 02 Double Flush to LO278907/LO310410	Test #2 City Segment	City Lap #1
		City Lap #2
		City Lap #3
Truck 01 Drain and fill to LO272251/LO310413	Baseline #2 Highway Segment	Highway Lap #1
		Highway Lap #2
		Highway Lap #3
Truck 02 Double Flush to LO272251/LO310413	Baseline #2 City Segment	City Lap #1
		City Lap #2
		City Lap #3

The Weather data during the segments was obtained from a portable weather station set on the interior of the track. The weather data includes: air temperature, wind speed, and relative humidity. No weather corrections were performed on the fuel economy data. The SAE J1321 (Revision 2012-02) Recommended Practice establishes weather limits for testing including limits in wind and temperature variation for each run, segment, and overall test. Due to the slower than typical vehicle speeds (< 60 mph) and an already modified procedure (< 50 mile route) the weather parameters were not used to determine lap validity. Collected weather data can be found in Appendix A along with the constraints set by the SAE J1321 (Revision 2012-02) Recommended Practice.

Each day prior to running the route, tire inflation pressures were checked and adjusted to the proper level. The trucks then performed a 1 hour warm-up as recommended by the SAE J1321 (Revision 2012-02) Recommended Practice. Additional inspections were performed on the vehicle prior to start, after warm-up, between test runs, and at the end of each day. This standard practice was performed to ensure validity in each vehicle test run.

III. TEST RESULTS

Each lap of testing resulted in a ratio of the fuel used by the Test Truck to the Control Truck (T/C ratio). A minimum of three T/C ratios were required for each segment. The resulting T/C ratios were used to calculate the fuel saved and the fuel improvement when comparing the baseline and test segments. Additionally, the T/C ratios were used to determine a 95% confidence interval for each result per the J1321 procedure. Only valid laps were considered in the analysis of the fuel consumption data. A lap was considered valid if the lap time fell within 0.25% of the first baseline run for the truck and the first baseline run time could also not differ more than 0.50% between Truck 01 and Truck 02. A summary of the resulting T/C ratios can be seen in Table 4. The T/C ratios and lap times are shown in Appendix B. A summary of the test results are shown in Table 5 and Figure 3. For consistency, both test segments are compared to the first baseline segment.

Table 4: Resulting T/C Ratios

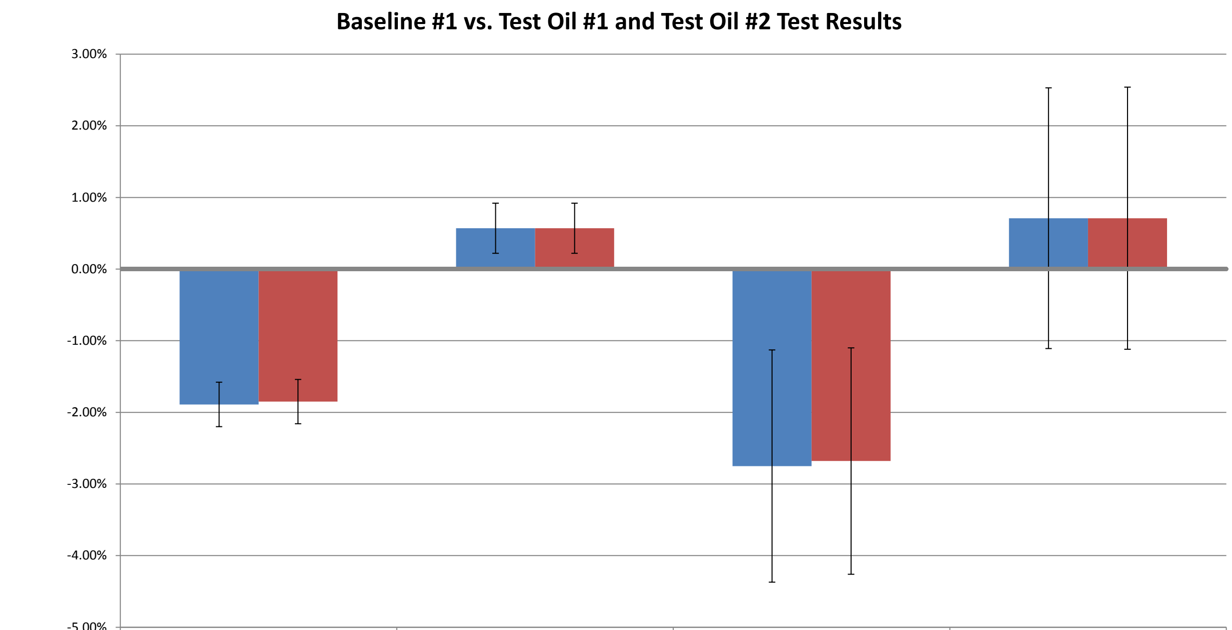
Baseline (Highway) Segment #1					
Run #1		Run #2		Run #3	
Fuel Consumed by Test Truck 64.30 lbs	Fuel Consumed by Control Truck 68.40 lbs	Fuel Consumed by Test Truck 63.35 lbs	Fuel Consumed by Control Truck 67.50 lbs	Fuel Consumed by Test Truck 62.90 lbs	Fuel Consumed by Control Truck 66.80 lbs
Baseline (Highway) T/C Ratio #1 0.9401		Baseline (Highway) T/C Ratio #2 0.9385		Baseline (Highway) T/C Ratio #3 0.9416	
Average T/C Ratio for Baseline (Highway) Segment 0.9401					
Baseline (City) Segment #1					
Run #1		Run #2		Run #3	
70.30 lbs	74.05 lbs	69.15 lbs	73.35 lbs	68.20 lbs	72.95 lbs
0.9494		0.9427		0.9349	
0.9423					
Test (Highway) Segment #1					
Run #1		Run #2		Run #3	
66.40 lbs	69.25 lbs	65.70 lbs	68.60 lbs	64.40 lbs	67.30 lbs
0.9588		0.9577		0.9569	
0.9578					
Test (City) Segment #1					
Run #1		Run #2		Run #3	
71.75 lbs	74.55 lbs	70.10 lbs	72.45 lbs	69.55 lbs	71.35 lbs
0.9624		0.9676		0.9748	
0.9683					
Test (Highway) Segment #2					
Run #1		Run #2		Run #3	
62.55 lbs	66.85 lbs	61.45 lbs	65.85 lbs	61.50 lbs	65.75 lbs
0.9357		0.9332		0.9354	
0.9347					
Test (City) Segment #2					
Run #1		Run #2		Run #3	
67.80 lbs	73.00 lbs	67.20 lbs	71.95 lbs	68.55 lbs	72.60 lbs
0.9288		0.9340		0.9442	
0.9357					

Table 4: Resulting T/C Ratios Continued

Baseline (Highway) Segment #2					
Run #1		Run #2		Run #3	
61.90 lbs	65.60 lbs	61.30 lbs	63.95 lbs	61.20 lbs	65.15 lbs
0.9436		0.9586		0.9394	
0.9472					
Baseline (City) Segment #2					
Run #1		Run #2		Run #3	
70.40 lbs	73.65 lbs	69.55 lbs	72.80 lbs	67.75 lbs	71.75 lbs
0.9559		0.9554		0.9443	
0.9518					

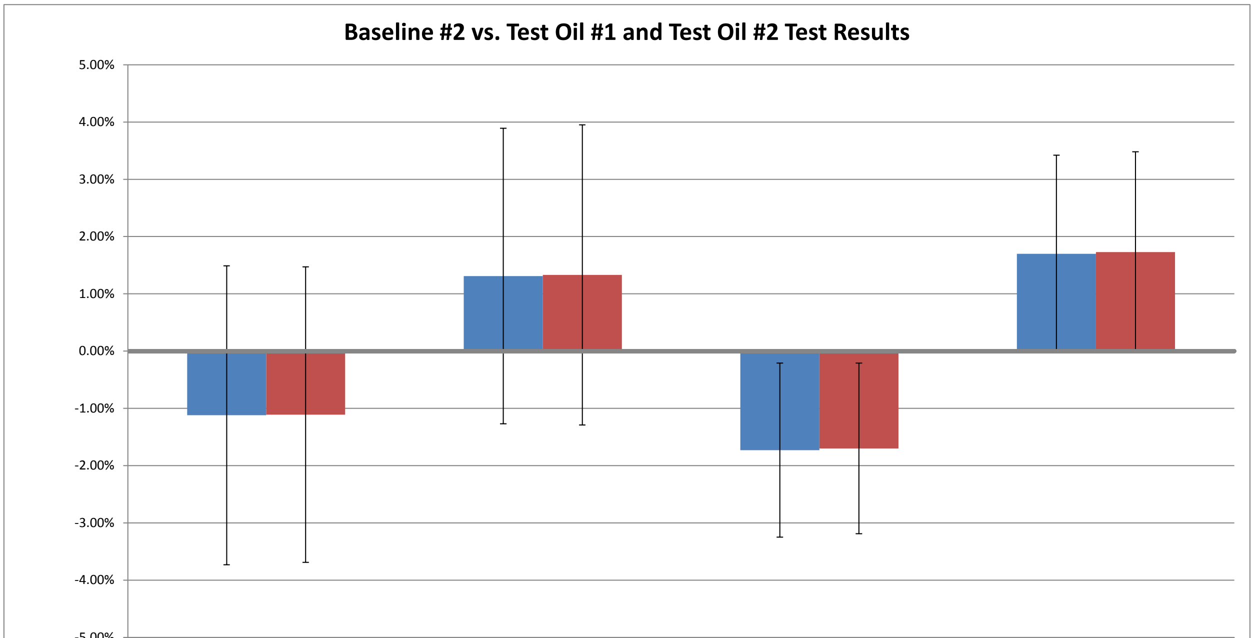
Table 5. Test Results

Baseline #1 vs. Test #1	Highway Route		Nominal	Confidence Interval	
		Fuel Saved	-1.89%	±	0.31%
		Improvement	-1.85%	±	0.31%
	City Route		Nominal	Confidence Interval	
		Fuel Saved	-2.75%	±	1.62%
		Improvement	-2.68%	±	1.58%
Baseline #1 vs. Test #2	Highway Route		Nominal	Confidence Interval	
		Fuel Saved	0.57%	±	0.35%
		Improvement	0.57%	±	0.35%
	City Route		Nominal	Confidence Interval	
		Fuel Saved	0.71%	±	1.82%
		Improvement	0.71%	±	1.83%
Baseline #2 vs. Test #1	Highway Route		Nominal	Confidence Interval	
		Fuel Saved	-1.12%	±	2.61%
		Improvement	-1.11%	±	2.58%
	City Route		Nominal	Confidence Interval	
		Fuel Saved	-1.73%	±	1.52%
		Improvement	-1.70%	±	1.49%
Baseline #2 vs. Test #2	Highway Route		Nominal	Confidence Interval	
		Fuel Saved	1.31%	±	2.58%
		Improvement	1.33%	±	2.62%
	City Route		Nominal	Confidence Interval	
		Fuel Saved	1.70%	±	1.72%
		Improvement	1.73%	±	1.75%



	Test #1 Highway	Test #2 Highway	Test #1 City	Test #2 City
Fuel Saved	-1.89% ± 0.31%	0.57% ± 0.35%	-2.75% ± 1.62%	0.71% ± 1.82%
Improvement	-1.85% ± 0.31%	0.57% ± 0.35%	-2.68% ± 1.58%	0.71% ±1.83%

Figure 3. Test Results



	Test #1 Highway	Test #2 Highway	Test #1 City	Test #2 City
Fuel Saved	-1.12% ± 2.61%	1.31% ± 2.58%	-1.73% ± 1.52%	1.70% ± 1.72%
Improvement	-1.11% ± 2.581%	1.33% ± 2.62%	-1.70% ± 1.49%	1.73% ±1.75%

Figure 4. Test Results

Appendix A
Weather Data

Test #1 Highway Weather Data Summary

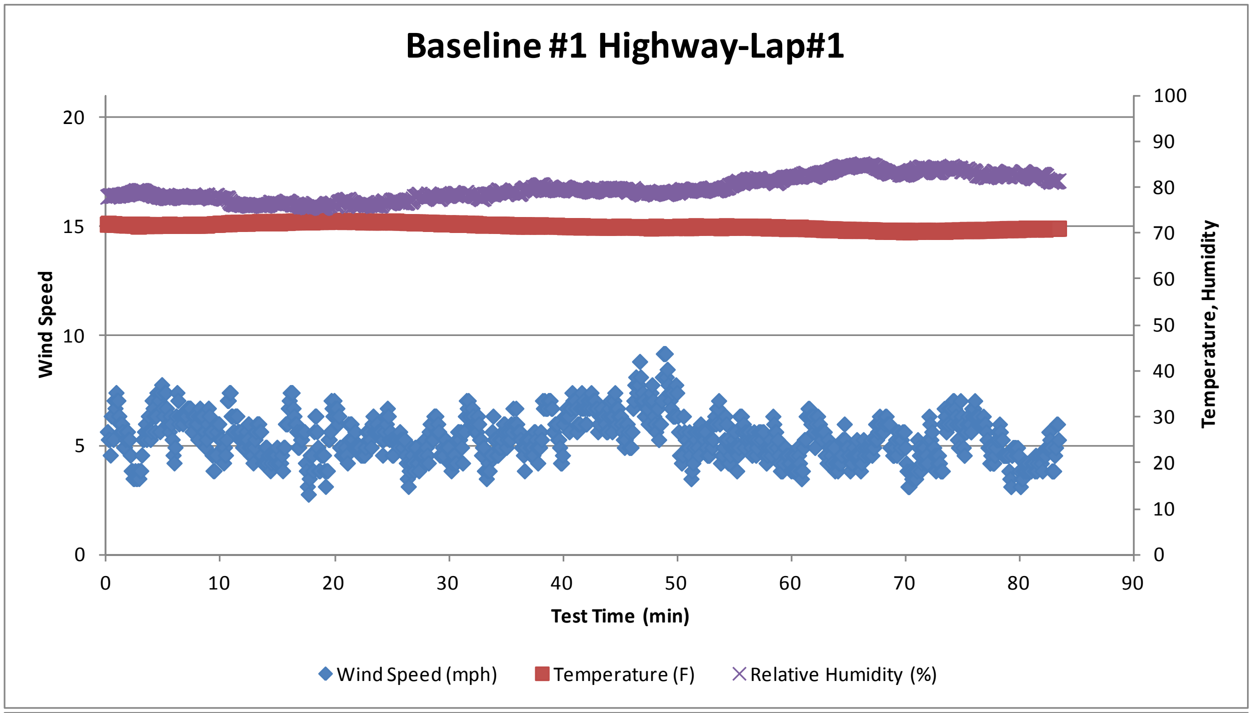
Baseline #1 Highway Segment and Test #1 Highway Segment

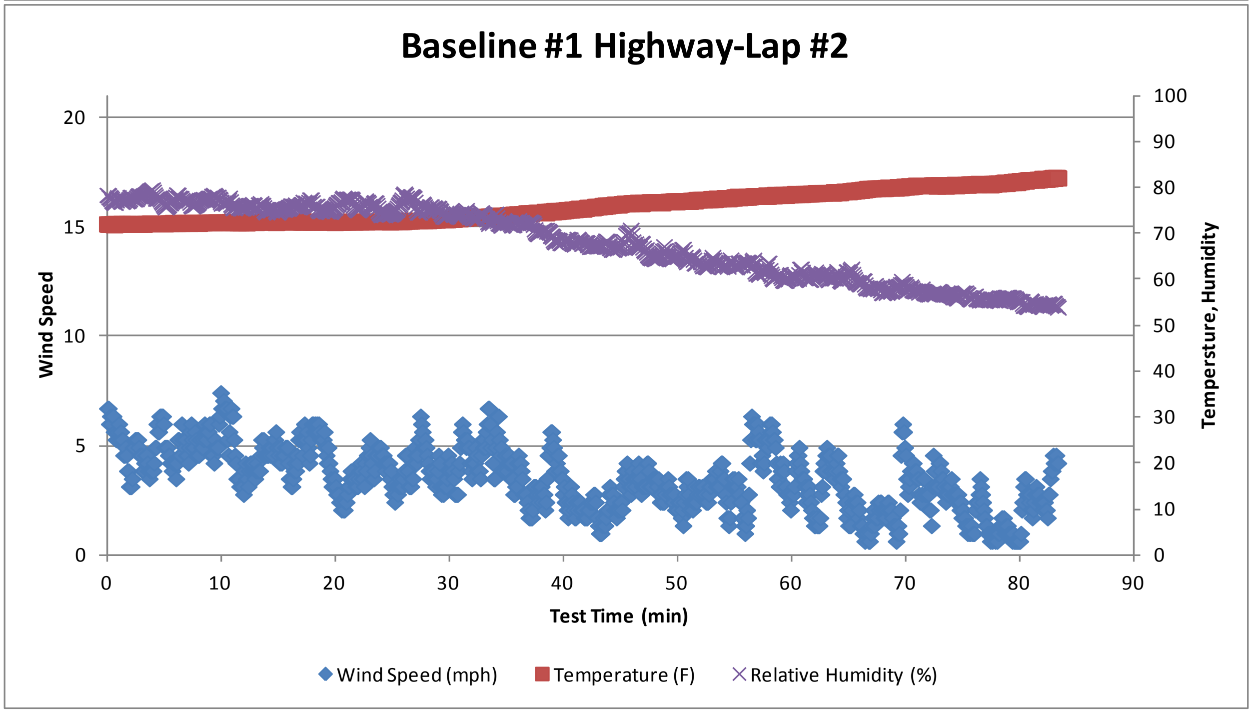
Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	5.42	2.77	9.21	---	70.40	72.80	2.40	79.75
Run #2	3.64	0.63	10.28	1.78	71.90	84.20	12.30	64.09
Run #3	5.03	0.63	13.50	1.78	81.50	86.50	5.00	47.76
Segment	4.69	0.63	13.50	1.78	70.40	86.50	16.10	63.87
Constraint	**≤12 (mph)**	**na (mph)**	**≤15 (mph)**	**≤5 (mph)**	**≥40° (F)**	**≤100° (F)**	**≤30° (F)**	**na (%)**

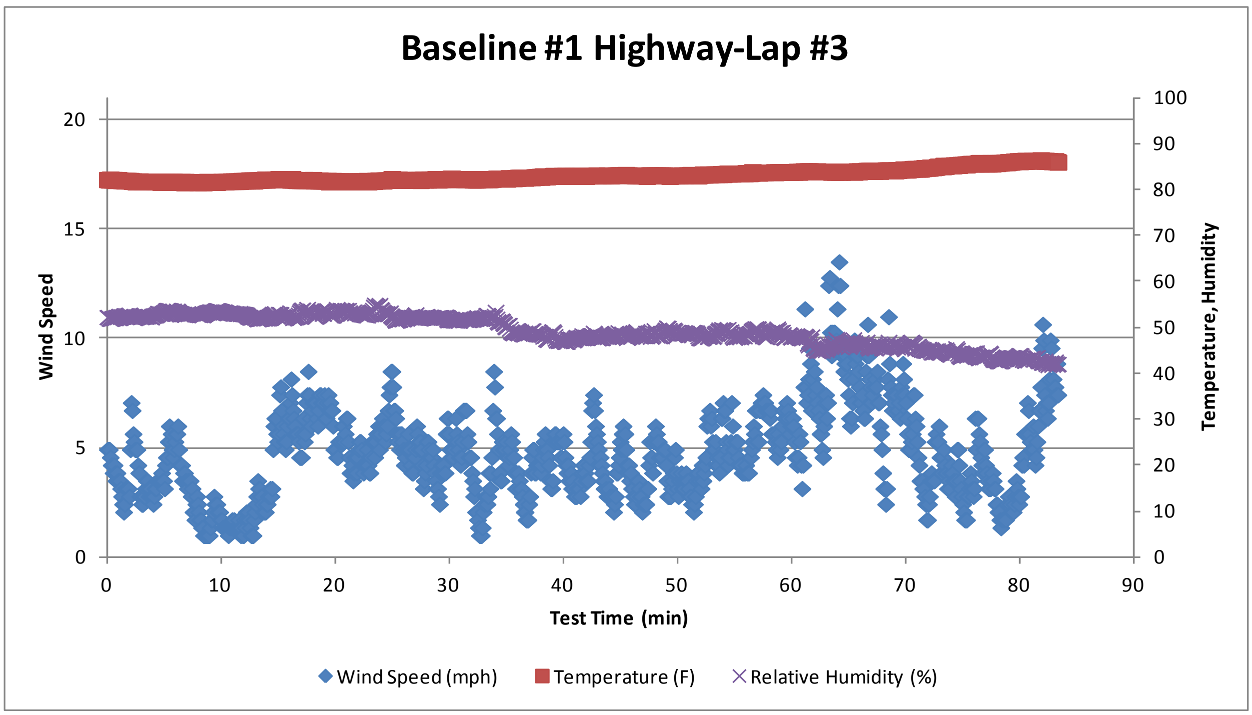
Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	*13.16	7.42	*18.86	---	73.90	77.50	3.60	65.25
Run #2	*12.67	6.71	*20.29	0.49	77.60	83.90	6.30	52.14
Run #3	11.08	3.13	*19.21	2.08	84.10	89.60	5.50	40.40
Segment	*12.31	3.13	*20.29	2.08	73.90	89.60	15.70	52.59
Constraint	**≤12 (mph)**	**na (mph)**	**≤15 (mph)**	**≤5 (mph)**	**≥40° (F)**	**≤100° (F)**	**≤30° (F)**	**na (%)**

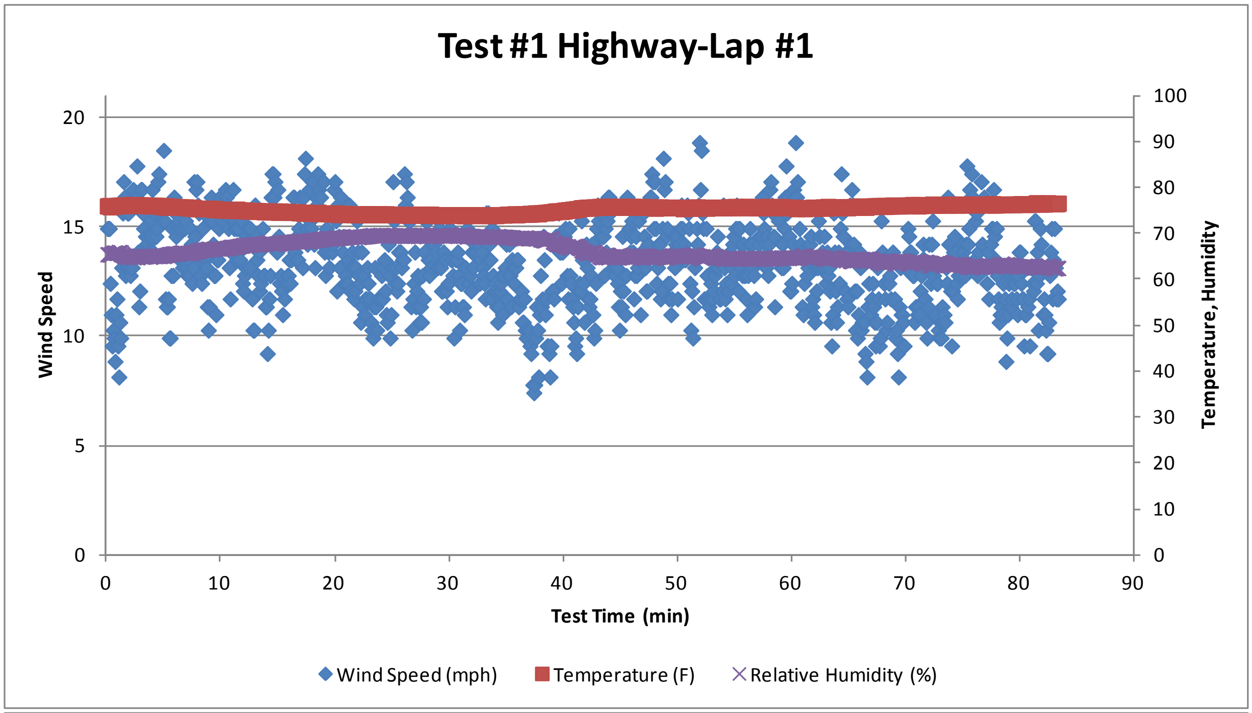
Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	8.50	0.63	*20.29	*9.53	70.40	89.60	19.20	58.23
Constraint	**≤12 (mph)**	**na (mph)**	**≤15 (mph)**	**≤5 (mph)**	**≥40° (F)**	**≤100° (F)**	**≤30° (F)**	**na (%)**

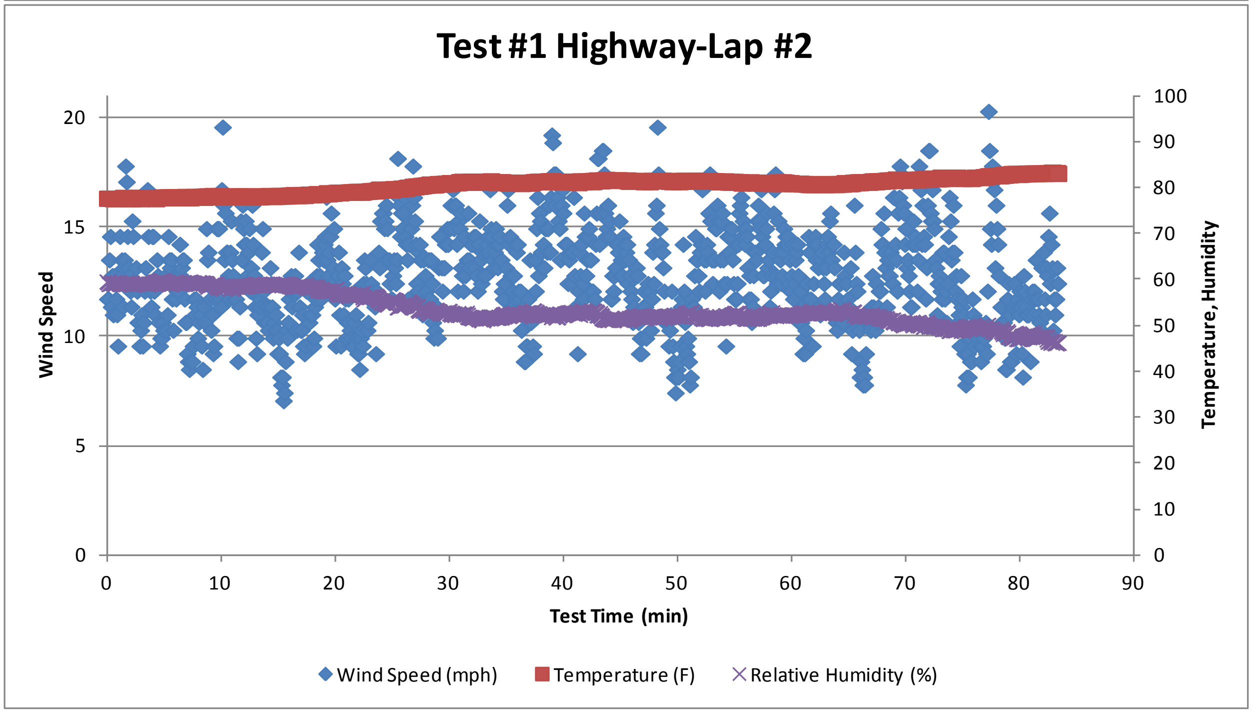
*Indicates weather parameters that are out of the SAE J1321 (Revision 2012-02) Recommendation

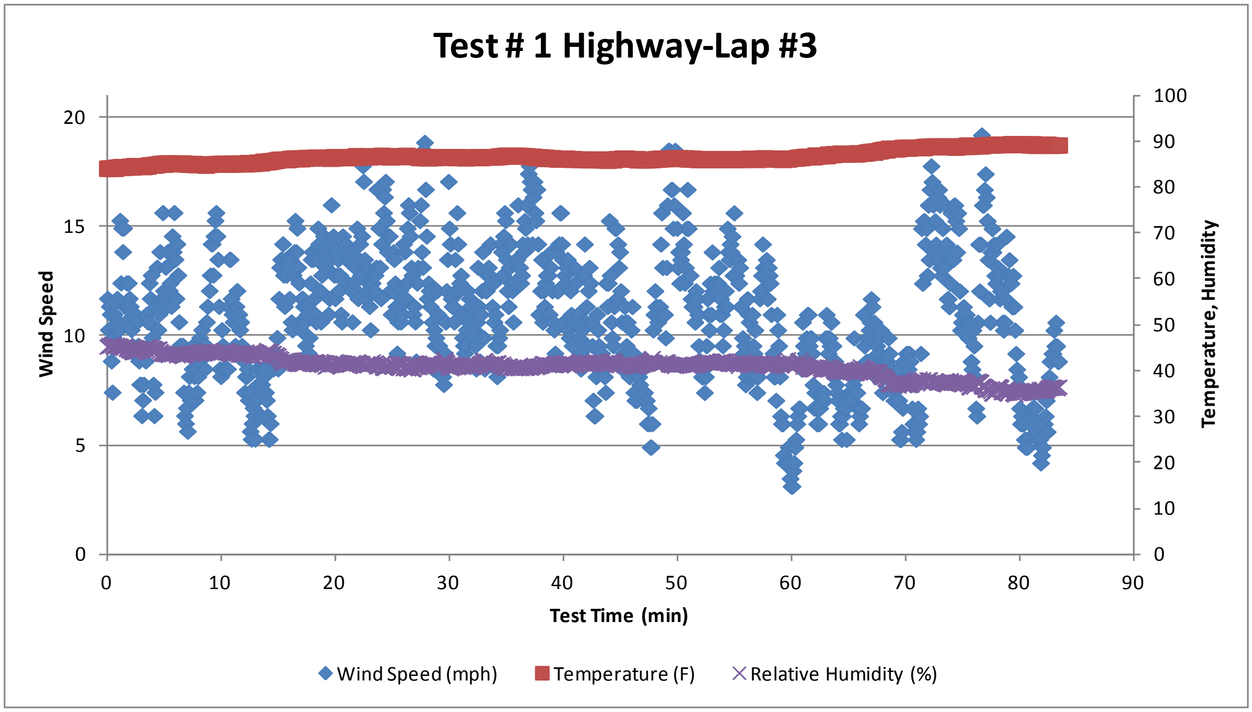

Baseline #1 Highway-Lap#1
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #1 Highway-Lap #2
Wind Speed
Tempersture, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #1 Highway-Lap #3
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
80
90
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test #1 Highway-Lap #1
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test #1 Highway-Lap #2
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test # 1 Highway-Lap #3
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

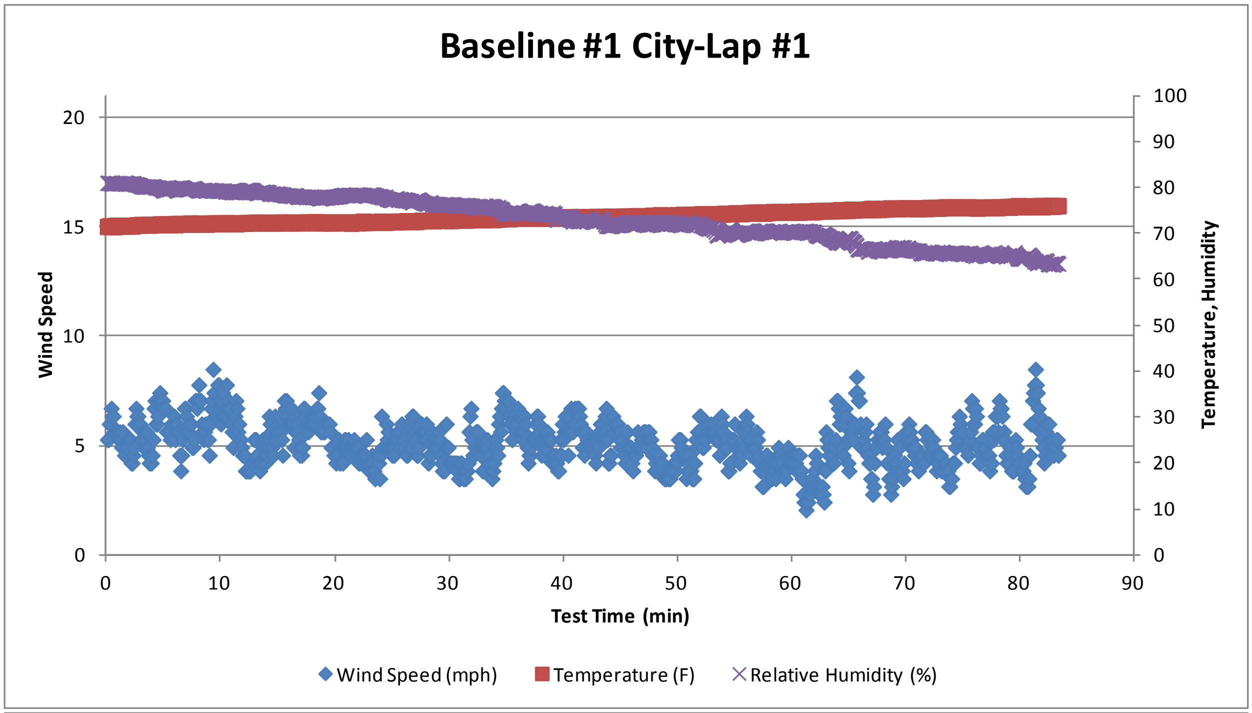
Test #1 City Weather Data Summary
Baseline #1 City Segment and Test #1 City Segment

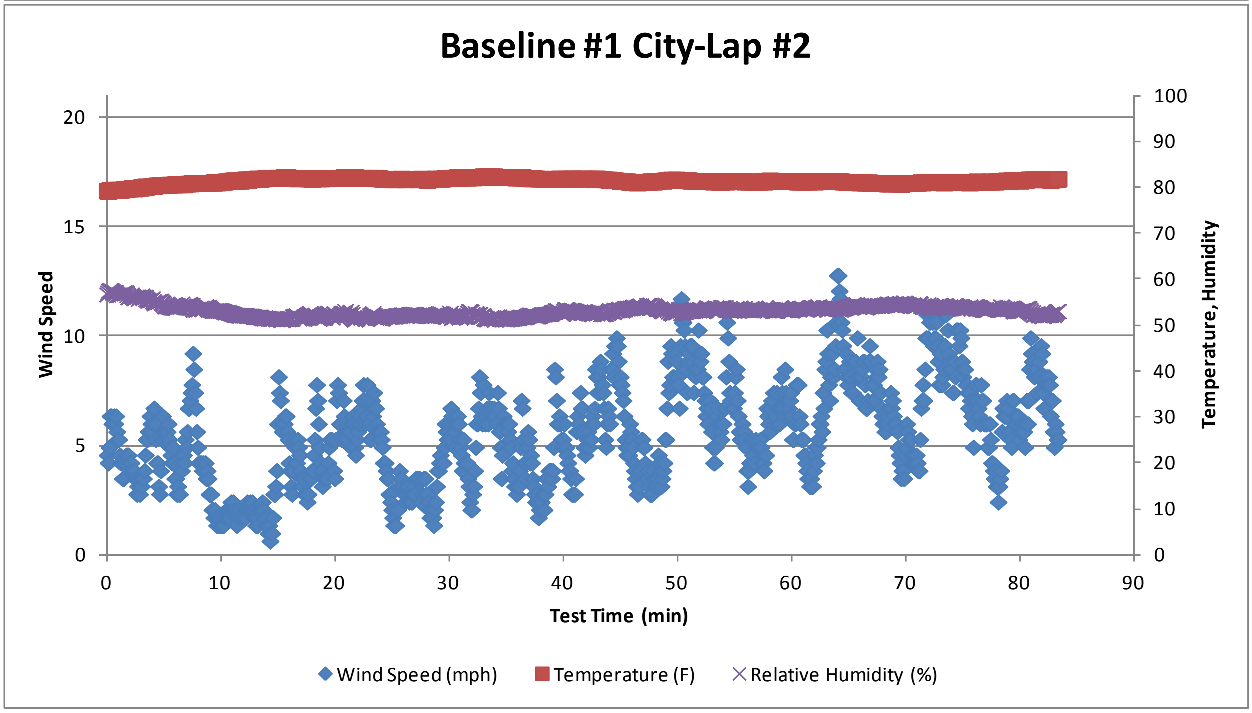
Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	5.10	1.70	9.56	---	71.50	79.10	7.60	69.62
Run #2	5.87	0.63	12.78	0.77	79.20	82.60	3.40	52.81
Run #3	5.26	0.63	13.85	0.77	83.90	90.20	6.30	40.47
Segment	5.41	0.63	13.85	0.77	71.50	90.20	18.70	54.30
Constraint	**≤12 (mph)**	**na (mph)**	**≤15 (mph)**	**≤5 (mph)**	**≥40° (F)**	**≤100° (F)**	**≤30° (F)**	**na (%)**

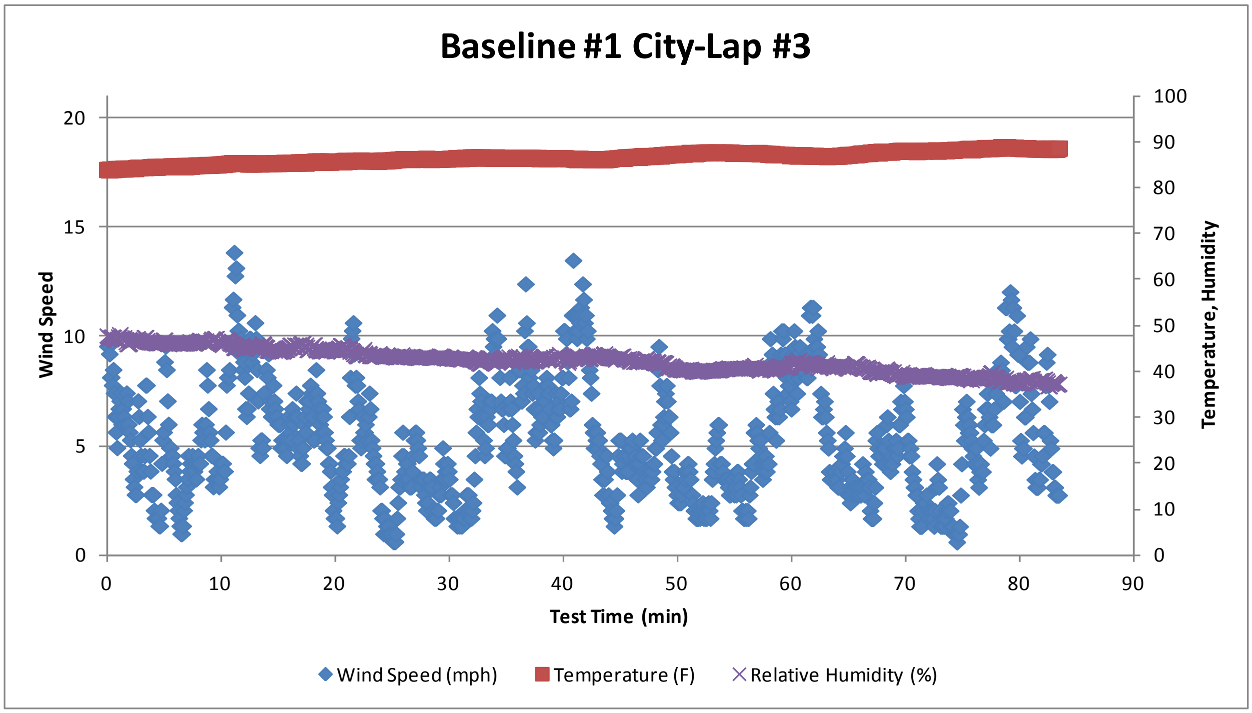
Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	11.39	5.28	*16.36	---	73.90	84.20	10.30	56.30
Run #2	6.73	0.99	14.93	4.66	83.90	91.20	7.30	35.84
Run #3	5.70	0.99	13.14	*5.68	90.70	96.50	5.80	27.78
Segment	7.94	0.99	*16.36	*5.68	73.90	96.50	22.60	39.97
Constraint	**≤12 (mph)**	**na (mph)**	**≤15 (mph)**	**≤5 (mph)**	**≥40° (F)**	**≤100° (F)**	**≤30° (F)**	**na (%)**

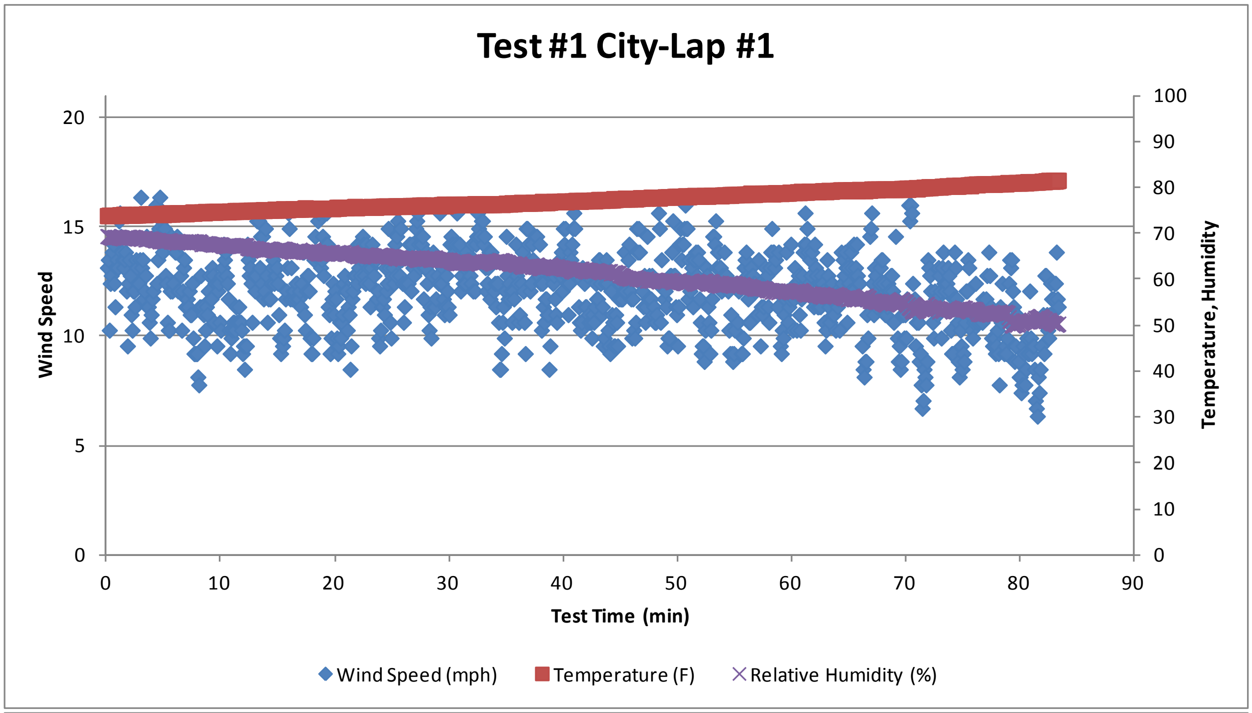
Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	6.68	0.63	*16.36	*6.28	71.50	96.50	25.00	47.14
Constraint	**≤12 (mph)**	**na (mph)**	**≤15 (mph)**	**≤5 (mph)**	**≥40° (F)**	**≤100° (F)**	**≤30° (F)**	**na (%)**

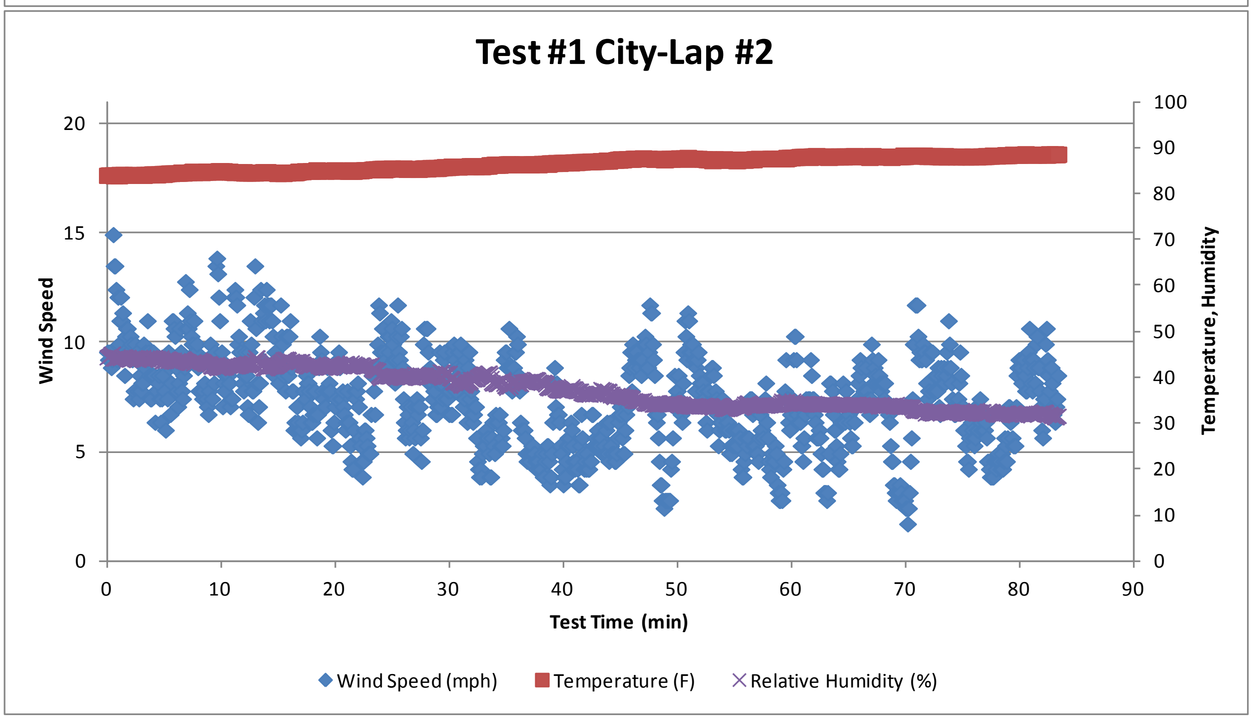
*Indicates weather parameters that are out of the SAE J1321 (Revision 2012-02) Recommendation

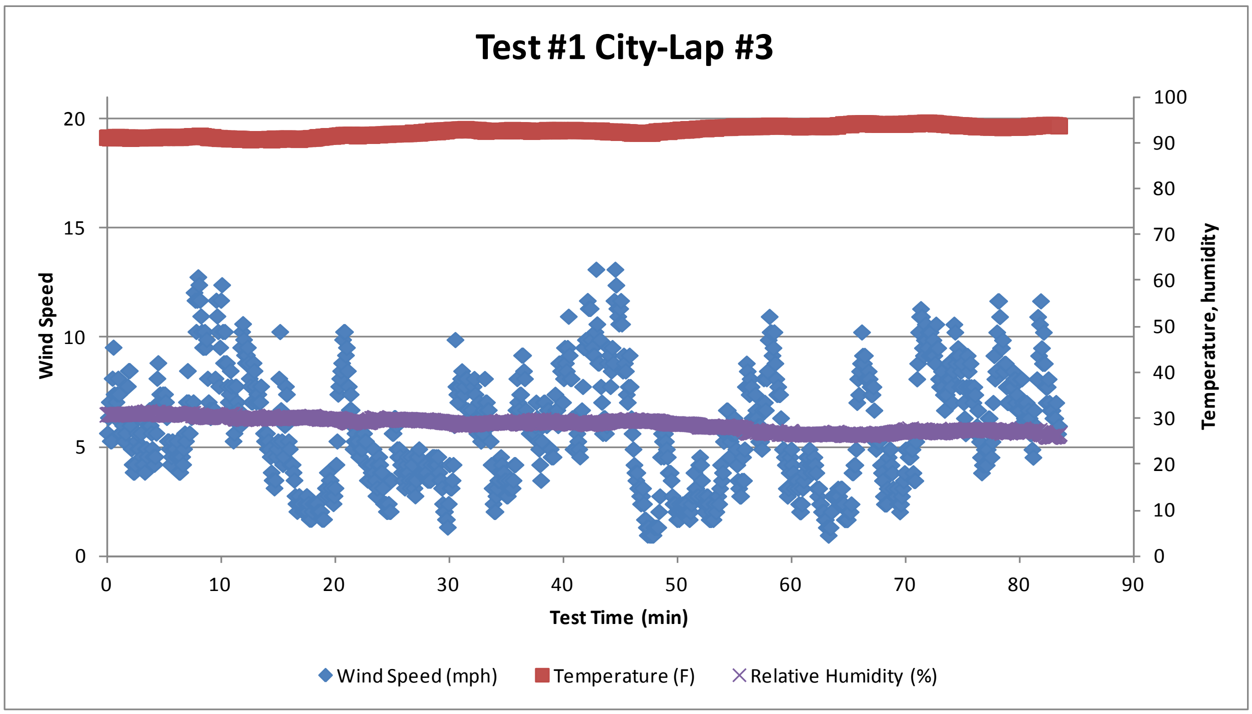

Baseline #1 City-Lap #1
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #1 City-Lap #2
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #1 City-Lap #3
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
80
90
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test #1 City-Lap #1
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test #1 City-Lap #2
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test #1 City-Lap #3
Wind Speed
Temperature, humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

Test #2 Highway Weather Data Summary

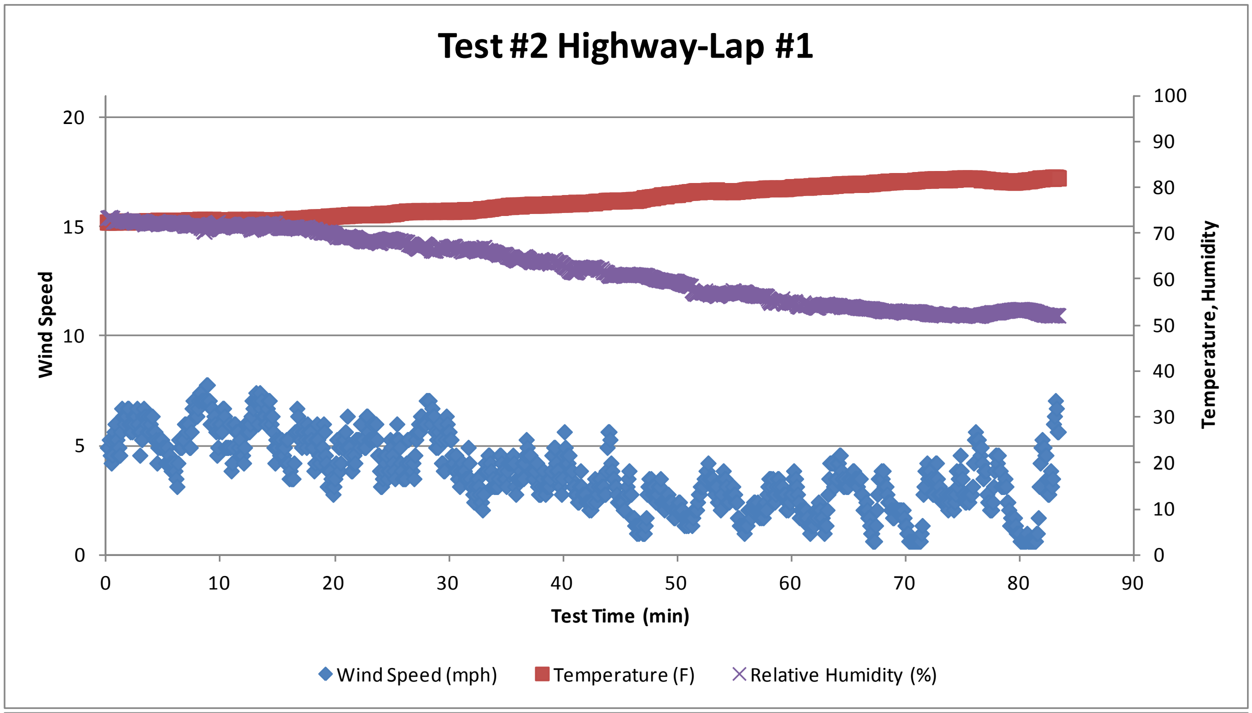
Baseline #1 Highway Segment and Test #2 Highway Segment

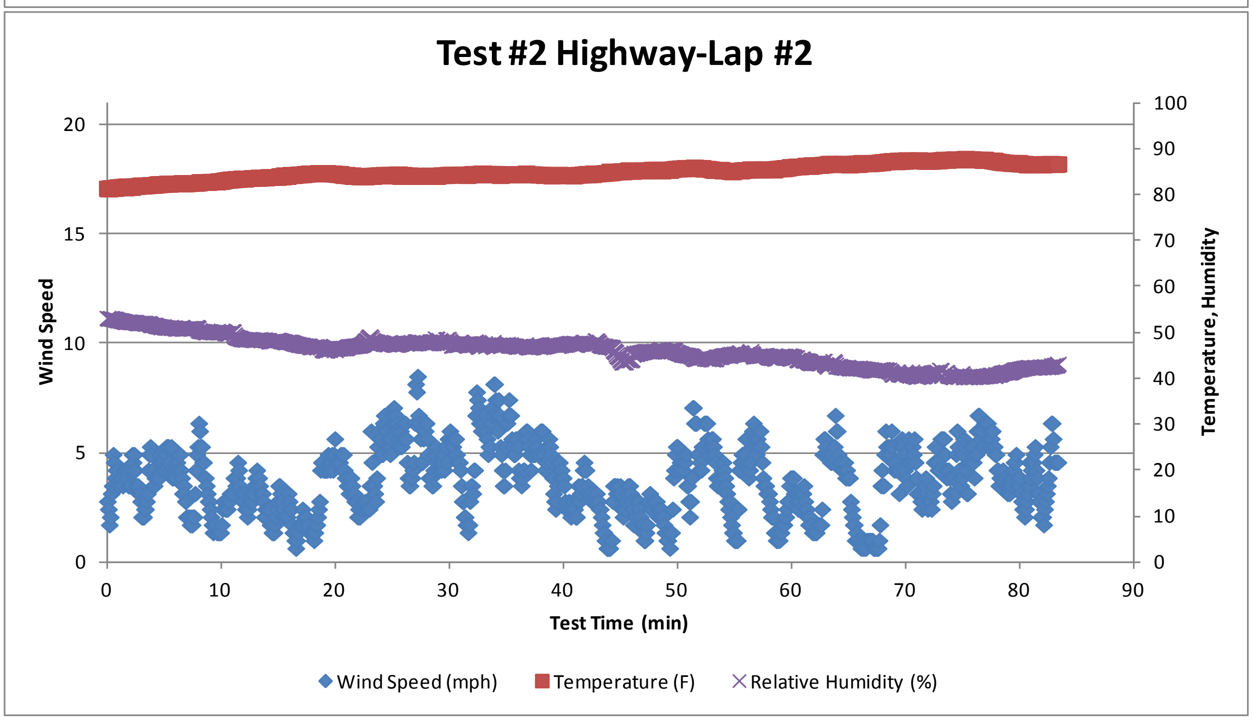
Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	5.42	2.77	9.21	---	70.40	72.80	2.40	79.75
Run #2	3.64	0.63	10.28	1.78	71.90	84.20	12.30	64.09
Run #3	5.03	0.63	13.50	1.78	81.50	86.50	5.00	47.76
Segment	4.69	0.63	13.50	1.78	70.40	86.50	16.10	63.87
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

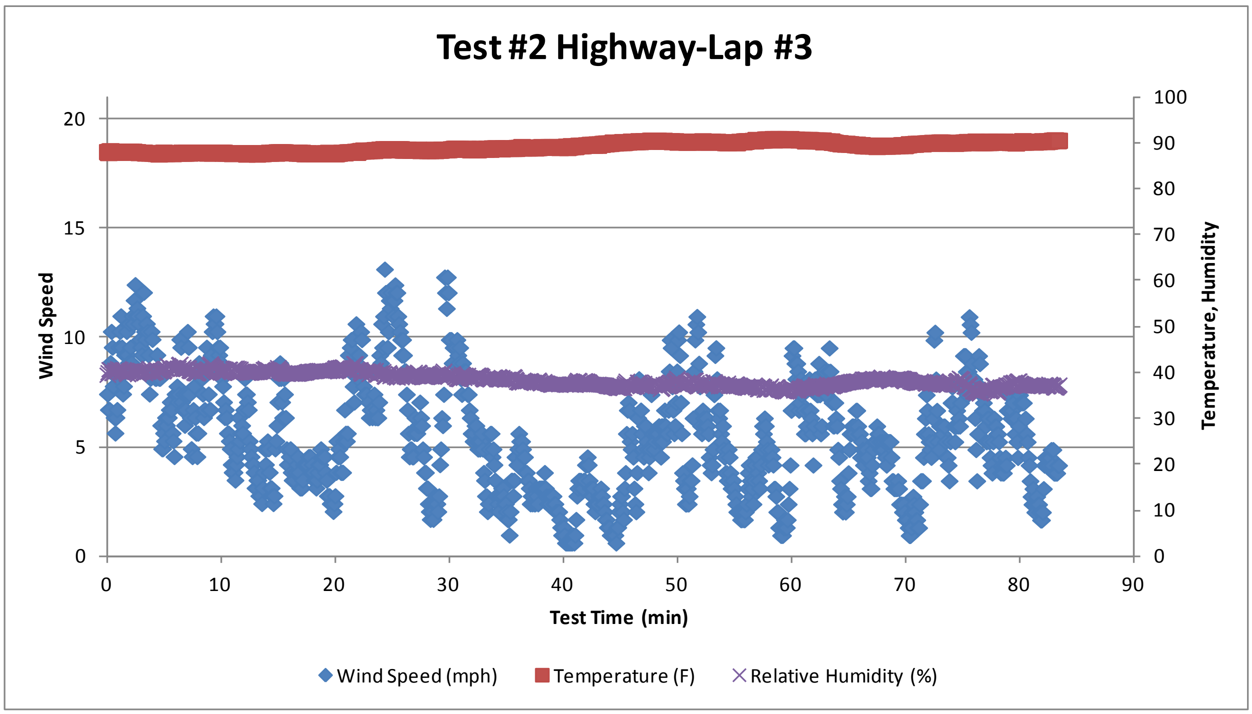
Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	3.74	0.63	7.78	---	72.50	82.70	10.20	60.51
Run #2	3.89	0.63	10.64	0.15	81.30	88.10	6.80	44.97
Run #3	5.69	0.63	13.14	1.95	87.60	91.60	4.00	38.02
Segment	4.44	0.63	13.14	1.95	72.50	91.60	19.10	47.84
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	4.57	0.63	13.50	2.05	70.40	91.60	21.20	55.85
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

*Indicates weather parameters that are out of the SAE J1321 (Revision 2012-02) Recommendation


Test #2 Highway-Lap #1
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test #2 Highway-Lap #2
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test #2 Highway-Lap #3
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

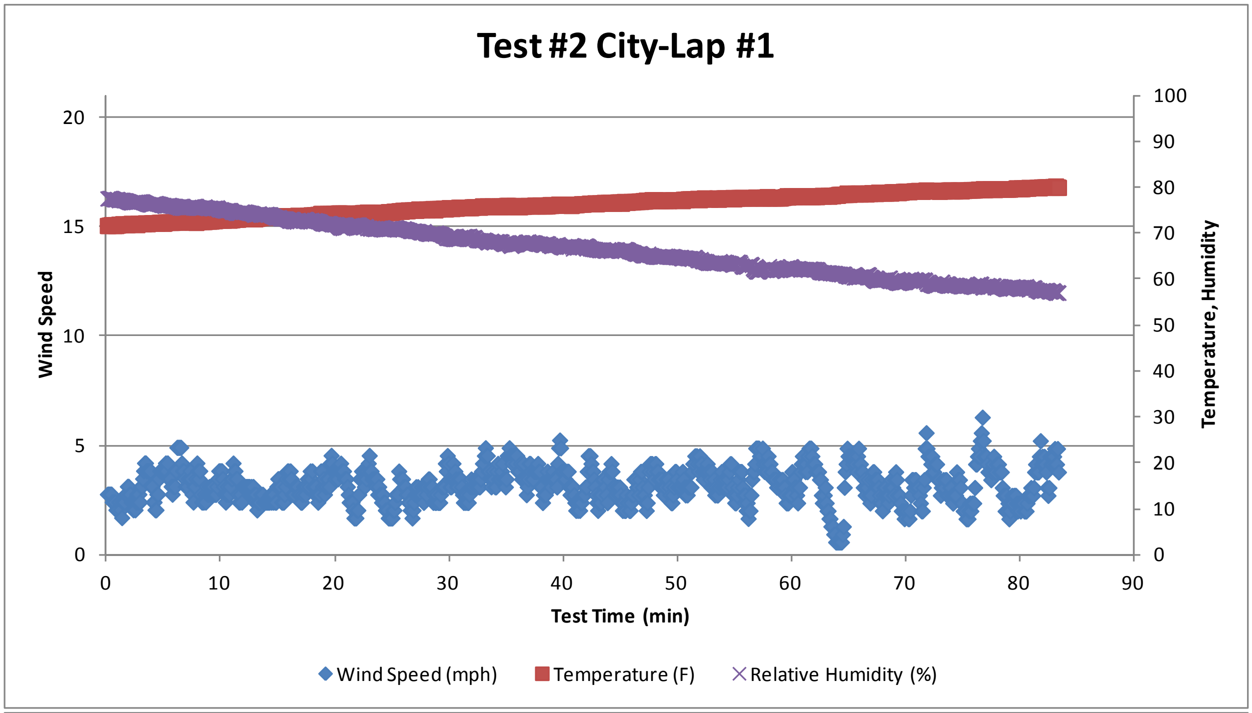
Test #2 City Weather Data Summary
Baseline #1 City Segment and Test #2 City Segment

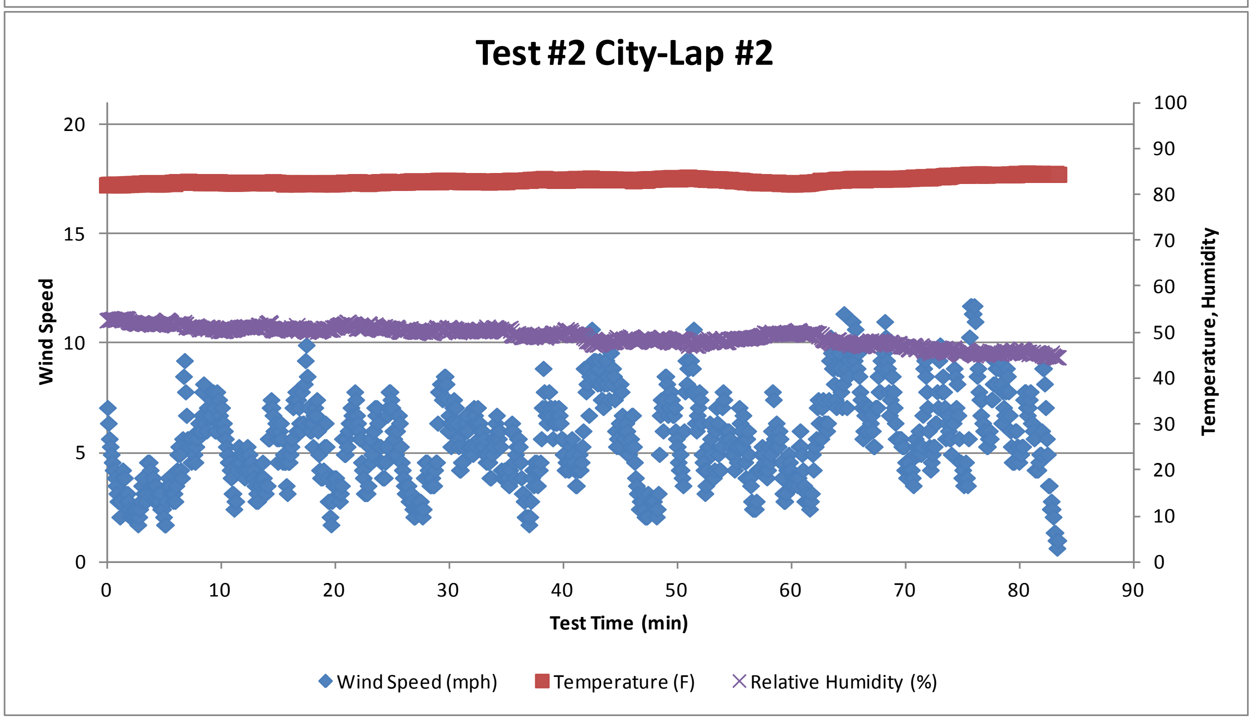
Baseline Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	5.10	1.70	9.56	---	71.50	79.10	7.60	69.62
Run #2	5.87	0.63	12.78	0.77	79.20	82.60	3.40	52.81
Run #3	5.26	0.63	13.85	0.77	83.90	90.20	6.30	40.47
Segment	5.41	0.63	13.85	0.77	71.50	90.20	18.70	54.30
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

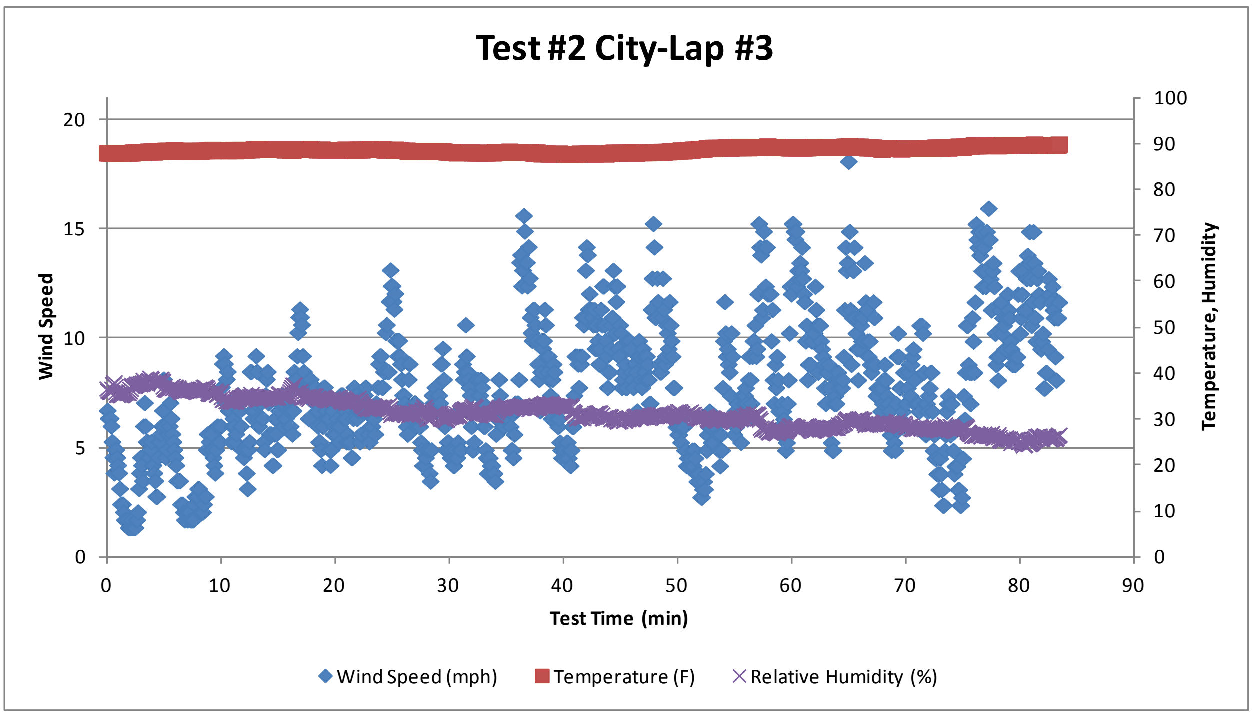
Test Segment	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	3.42	0.63	7.42	---	71.70	82.30	10.60	63.46
Run #2	5.17	0.63	11.71	1.75	82.10	87.70	5.60	47.10
Run #3	8.39	1.35	*18.14	4.97	87.80	91.60	3.80	29.22
Segment	5.66	0.63	*18.14	4.97	71.70	91.60	19.90	46.59
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	5.54	0.63	18.14	4.97	71.50	91.60	20.10	50.45
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

*Indicates weather parameters that are out of the SAE J1321 (Revision 2012-02) Recommendation


Test #2 City-Lap #1
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test #2 City-Lap #2
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Test #2 City-Lap #3
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

Baseline Highway Weather Data Comparison

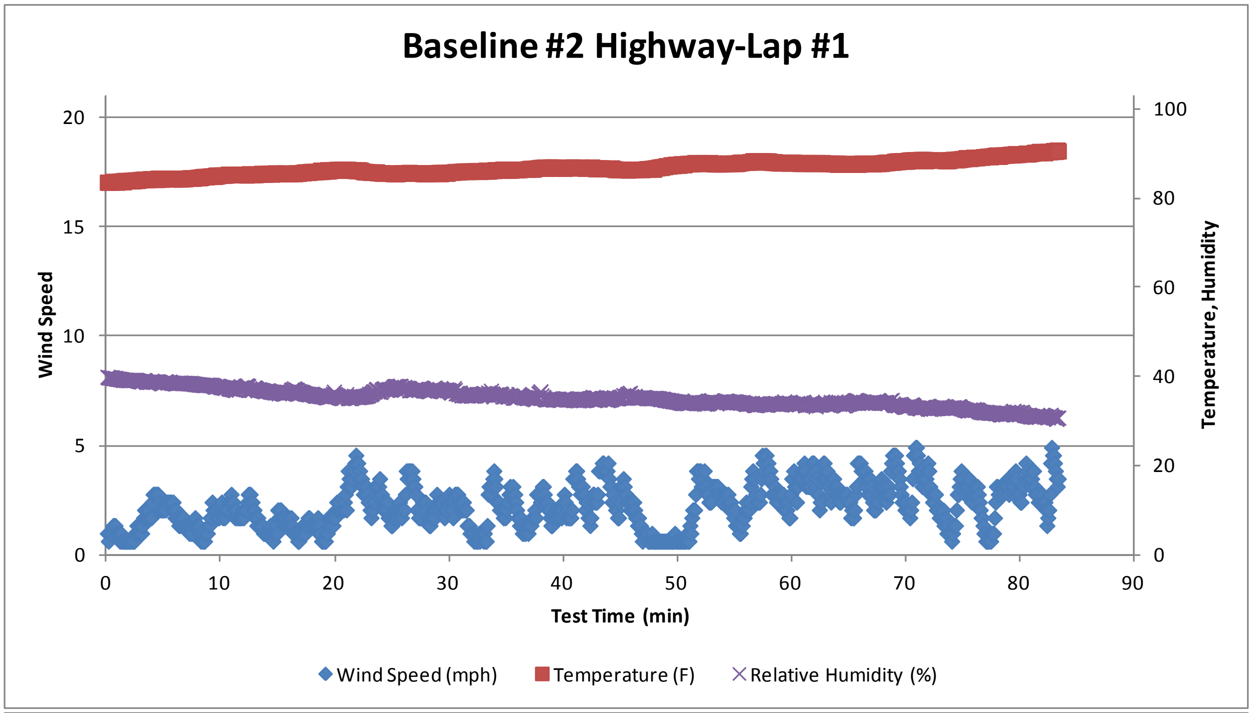
Baseline #1 Highway Segment and Baseline #2 Highway Segment

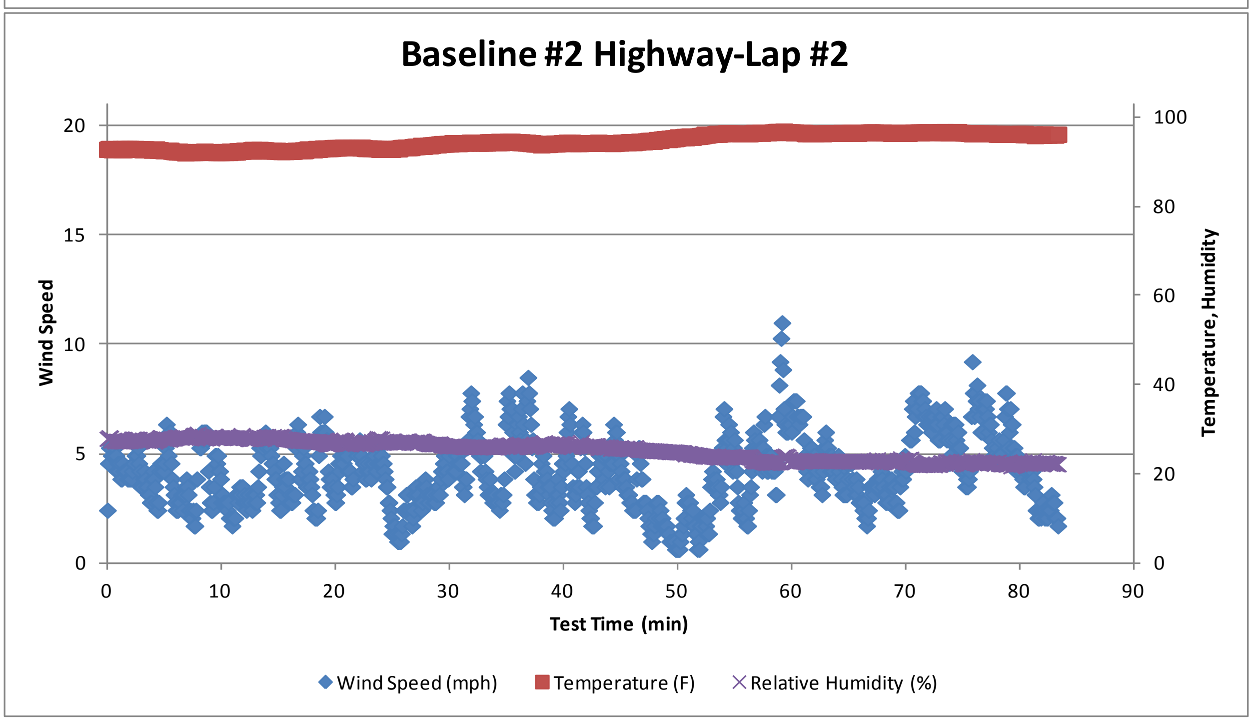
Baseline Segment #1	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	5.42	2.77	9.21	---	70.40	72.80	2.40	79.75
Run #2	3.64	0.63	10.28	1.78	71.90	84.20	12.30	64.09
Run #3	5.03	0.63	13.50	1.78	81.50	86.50	5.00	47.76
Segment	4.69	0.63	13.50	1.78	70.40	86.50	16.10	63.87
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

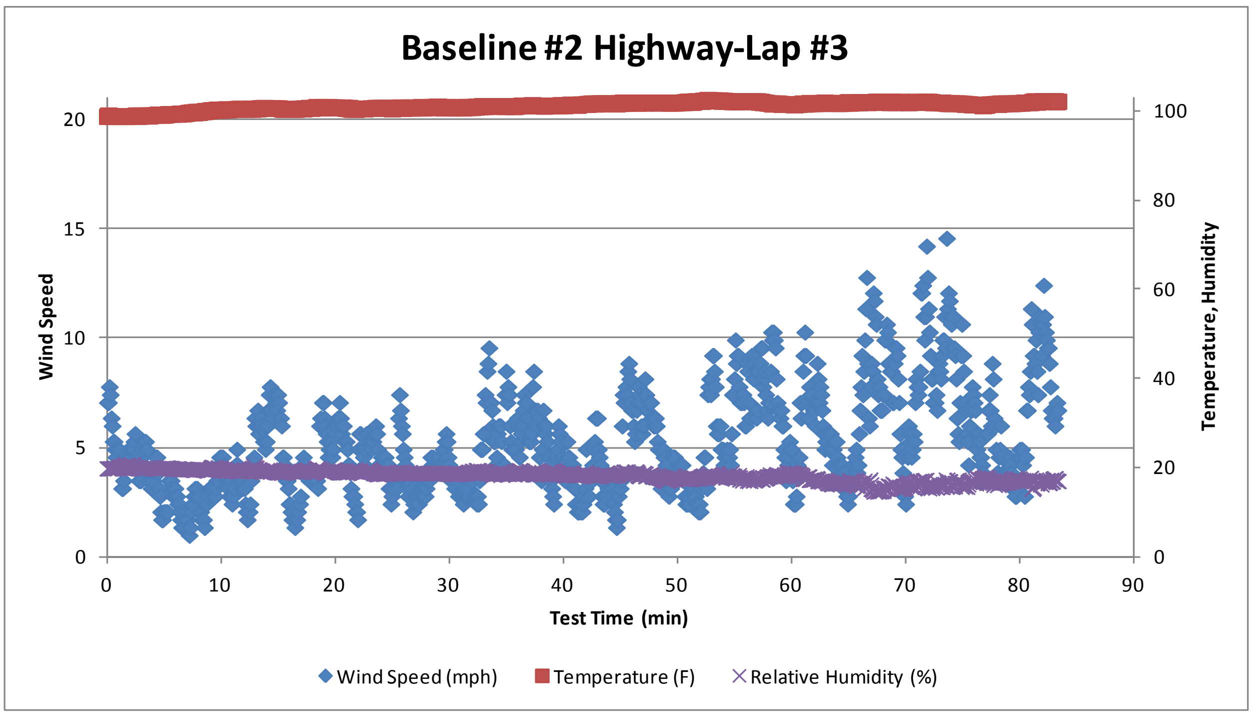
Baseline Segment #2	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	2.26	0.63	4.92	---	83.60	92.50	8.90	34.18
Run #2	4.01	0.63	10.99	1.76	92.00	99.50	7.50	24.55
Run #3	5.82	0.99	14.57	3.56	98.80	*102.60	3.80	17.86
Segment	4.03	0.63	14.57	3.56	83.60	*102.60	19.00	25.53
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	4.36	0.63	14.57	3.56	70.40	*102.60	*32.20	44.70
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

*Indicates weather parameters that are out of the SAE J1321 (Revision 2012-02) Recommendation


Baseline #2 Highway-Lap #1
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #2 Highway-Lap #2
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #2 Highway-Lap #3
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
20
40
60
80
100
0
10
20
30
40
50
60
70
80
90
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

Baseline City Weather Data Comparison

Baseline #1 City Segment and Baseline #2 City Segment

Baseline Segment #1	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	5.10	1.70	9.56	---	71.50	79.10	7.60	69.62
Run #2	5.87	0.63	12.78	0.77	79.20	82.60	3.40	52.81
Run #3	5.26	0.63	13.85	0.77	83.90	90.20	6.30	40.47
Segment	5.41	0.63	13.85	0.77	71.50	90.20	18.70	54.30
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Baseline Segment #2	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Run #1	6.77	2.42	*17.43	---	70.80	74.50	3.70	66.80
Run #2	4.45	0.99	12.07	2.32	75.50	86.90	11.40	47.88
Run #3	6.80	0.99	12.78	2.35	77.90	87.70	9.80	50.84
Segment	6.01	0.99	*17.43	2.35	70.80	87.70	16.90	55.18
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

Overall Data Summary	Mean Wind Speed	Min Wind Speed	Max Wind Speed	Variation in Wind Speed	Min Temp	Max Temp	Variation in Temp	Average Humidity
Overall	5.71	0.63	*17.43	2.35	70.80	90.20	19.40	54.74
Constraint	≤12 (mph)	na (mph)	≤15 (mph)	≤5 (mph)	≥40° (F)	≤100° (F)	≤30° (F)	na (%)

*Indicates weather parameters that are out of the SAE J1321 (Revision 2012-02) Recommendation

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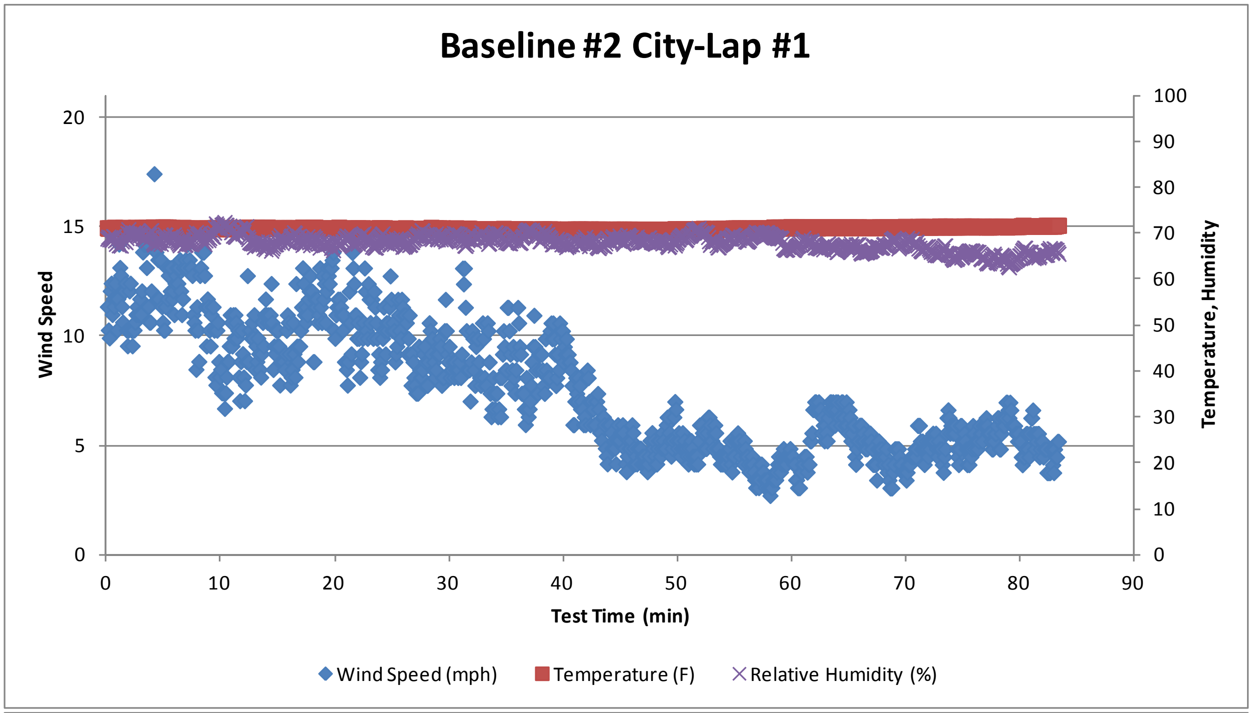
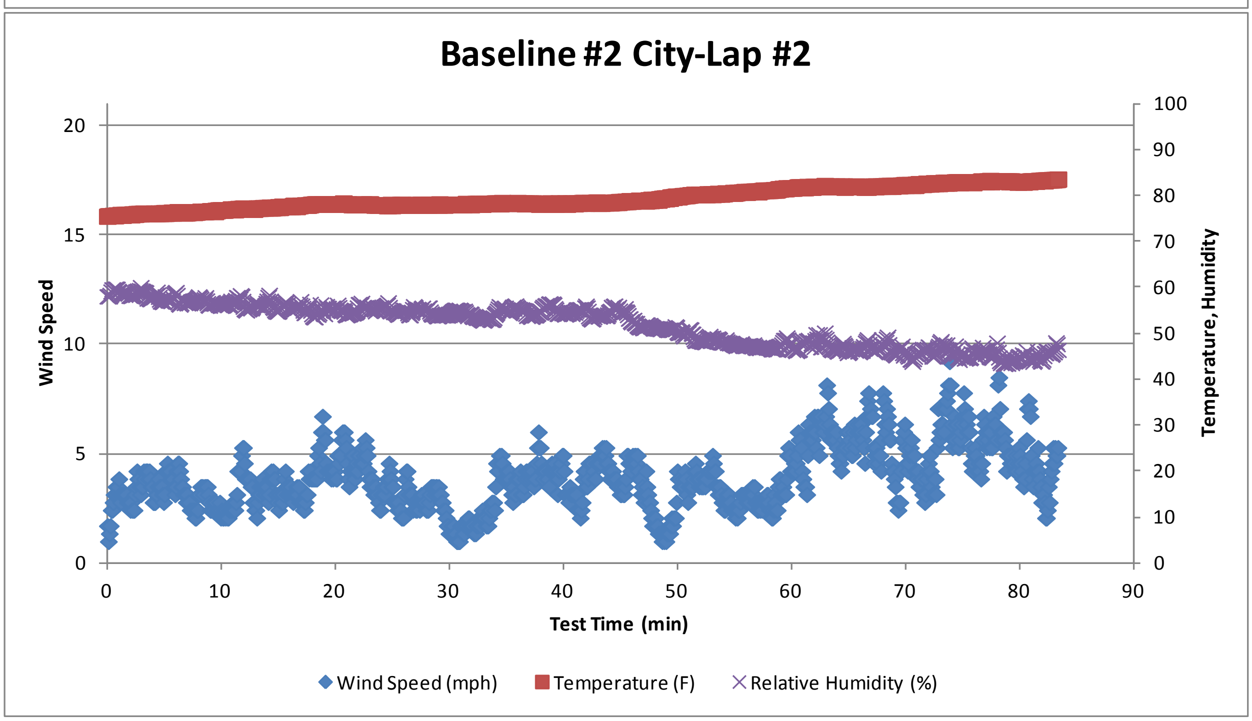
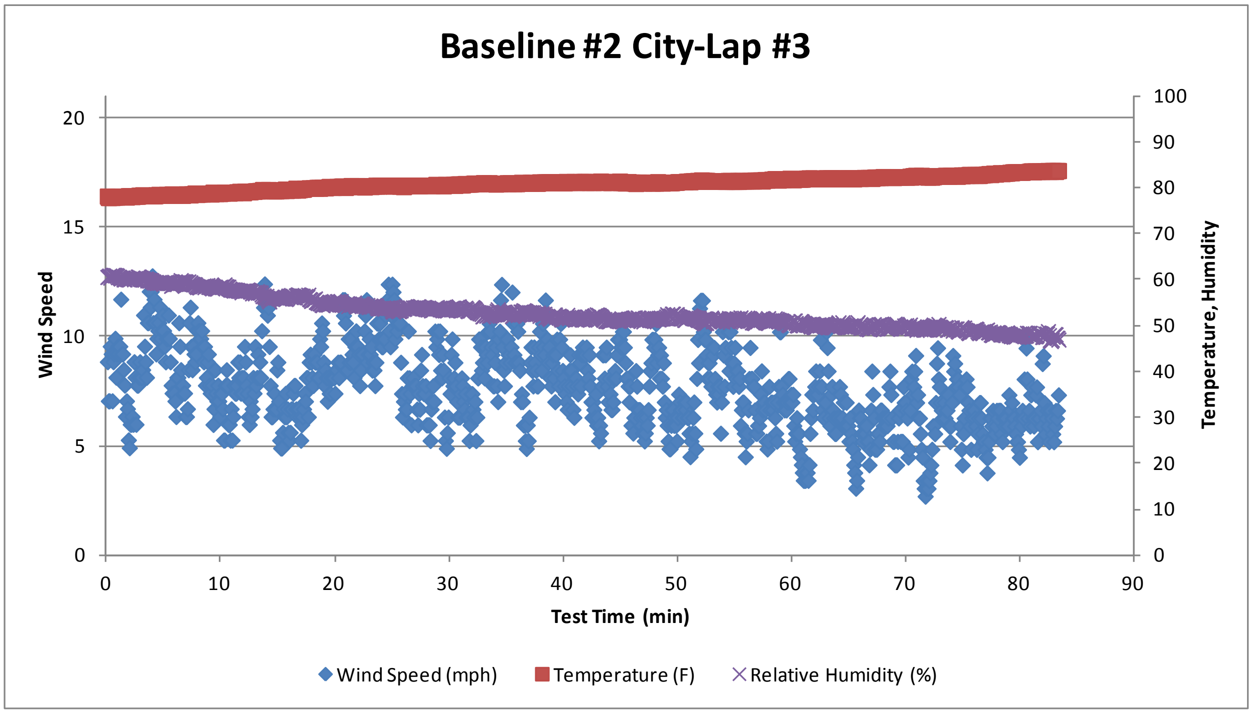

Baseline #2 City-Lap #1
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #2 City-Lap #2
Wind Speed
Temperature, Humidity
Test Time (min)
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)


Baseline #2 City-Lap #3
Wind Speed
Temperature, Humidity
Test Time (min)
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
80
90
Wind Speed (mph)
Temperature (F)
Relative Humidity (%)

Appendix B
T/C Ratios & Lap Times

Test #1 Highway TC Ratios and Lap Times
Baseline #1 Highway Segment and Test #1 Highway Segement

Baseline # 1 Highway Lap Times (Target Time: 1:27:12)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:27:11	1:27:09	0.038%	Truck 01	Truck 02
Run #2	1:27:11	1:27:05		0.000%	-0.076%
Run #3	1:27:10	1:27:09		-0.019%	0.000%

Test # 1 Highway Lap Times (Target Time: 1:27:12)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:27:11	1:27:11	0.000%	0.038%
Run #2	1:27:12	1:27:10	0.019%	0.019%
Run #3	1:27:11	1:27:11	0.000%	0.038%

Baseline # 1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	68.40	64.30	0.9401	
Run #2	67.50	63.35	0.9385	0.164%
Run #3	66.80	62.90	0.9416	-0.166%

Test # 1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	69.25	66.40	0.9588	
Run #2	68.60	65.70	0.9577	0.117%
Run #3	67.30	64.40	0.9569	0.202%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	-1.89%	± 0.31%
Improvement	-1.85%	± 0.31%

Test #1 City TC Ratios and Lap Times
Baseline #1 City Segment and Test #1 City Segement

Baseline # 1 City Lap Times (Target Time: 1:48:30)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:48:36	1:48:32	0.061%	Truck 01	Truck 02
Run #2	1:48:30	1:48:30		-0.092%	-0.031%
Run #3	1:48:31	1:48:31		-0.077%	-0.015%

Test # 1 City Lap Times (Target Time: 1:48:30)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:48:31	1:48:32	-0.077%	0.000%
Run #2	1:48:32	1:48:31	-0.061%	-0.015%
Run #3	1:48:31	1:48:31	-0.077%	-0.015%

Baseline # 1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	74.05	70.30	0.9494	
Run #2	73.35	69.15	0.9427	0.697%
Run #3	72.95	68.20	0.9349	1.524%

Test # 1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	74.55	71.75	0.9624	
Run #2	72.45	70.10	0.9676	-0.532%
Run #3	71.35	69.55	0.9748	-1.281%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	-2.75%	± 1.62%
Improvement	-2.68%	± 1.58%

Test #2 Highway TC Ratios and Lap Times
Baseline #1 Highway Segment and Test #2 Highway Segement

Baseline # 1 Highway Lap Times (Target Time: 1:27:12)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:27:11	1:27:09	0.038%	Truck 01	Truck 02
Run #2	1:27:11	1:27:05		0.000%	-0.076%
Run #3	1:27:10	1:27:09		-0.019%	0.000%

Test # 2 Highway Lap Times (Target Time: 1:27:12)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:27:11	1:27:10	0.000%	0.019%
Run #2	1:27:10	1:27:10	-0.019%	0.019%
Run #3	1:27:11	1:27:10	0.000%	0.019%

Baseline # 1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	68.40	64.30	0.9401	
Run #2	67.50	63.35	0.9385	0.164%
Run #3	66.80	62.90	0.9416	-0.166%

Test # 2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	66.85	62.55	0.9357	
Run #2	65.85	61.45	0.9332	0.267%
Run #3	65.75	61.50	0.9354	0.034%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	0.57%	± 0.35%
Improvement	0.57%	± 0.35%

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Test #2 City TC Ratios and Lap Times
Baseline #1 City Segment and Test #2 City Segement

Baseline # 1 City Lap Times (Target Time: 1:48:30)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:48:36	1:48:32	0.061%	Truck 01	Truck 02
Run #2	1:48:30	1:48:30		-0.092%	-0.031%
Run #3	1:48:31	1:48:31		-0.077%	-0.015%

Test # 2 City Lap Times (Target Time: 1:48:30)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:48:33	1:48:32	-0.046%	0.000%
Run #2	1:48:32	1:48:32	-0.061%	0.000%
Run #3	1:48:30	1:48:32	-0.092%	0.000%

Baseline # 1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	74.05	70.30	0.9494	
Run #2	73.35	69.15	0.9427	0.697%
Run #3	72.95	68.20	0.9349	1.524%

Test # 2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	73.00	67.80	0.9288	
Run #2	71.95	67.20	0.9340	-0.561%
Run #3	72.60	68.55	0.9442	-1.663%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	0.71%	± 1.82%
Improvement	0.71%	± 1.83%

Test #1 Highway TC Ratios and Lap Times
Baseline #2 Highway Segment and Test #1 Highway Segement

Baseline # 2 Highway Lap Times (Target Time: 1:27:12)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:27:11	1:27:10	0.019%	Truck 01	Truck 02
Run #2	1:27:10	1:27:08		-0.019%	-0.038%
Run #3	1:27:11	1:27:11		0.000%	0.019%

Test # 1 Highway Lap Times (Target Time: 1:27:12)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:27:11	1:27:11	0.000%	0.019%
Run #2	1:27:12	1:27:10	0.019%	0.000%
Run #3	1:27:11	1:27:11	0.000%	0.019%

Baseline # 2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	65.60	61.90	0.9436	
Run #2	63.95	61.30	0.9586	-1.586%
Run #3	65.15	61.20	0.9394	0.448%

Test # 1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	69.25	66.40	0.9588	
Run #2	68.60	65.70	0.9577	0.117%
Run #3	67.30	64.40	0.9569	0.202%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	-1.12%	± 2.61%
Improvement	-1.11%	± 2.58%

Test #1 City TC Ratios and Lap Times
Baseline #2 City Segment and Test #1 City Segement

Baseline # 2 City Lap Times (Target Time: 1:48:30)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:48:30	1:48:31	0.015%	**Truck 01**	**Truck 02**
Run #2	1:48:33	1:48:31		0.046%	0.000%
Run #3	1:48:30	1:48:32		0.000%	0.015%

Test # 1 City Lap Times (Target Time: 1:48:30)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:48:31	1:48:32	0.015%	0.015%
Run #2	1:48:32	1:48:31	0.031%	0.000%
Run #3	1:48:31	1:48:31	0.015%	0.000%

Baseline # 2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	73.65	70.40	0.9559	
Run #2	72.80	69.55	0.9554	0.054%
Run #3	71.75	67.75	0.9443	1.216%

Test # 1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	74.55	71.75	0.9624	
Run #2	72.45	70.10	0.9676	-0.532%
Run #3	71.35	69.55	0.9748	-1.281%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	-1.73%	± 1.52%
Improvement	-1.70%	± 1.49%

Test #2 Highway TC Ratios and Lap Times
Baseline #2 Highway Segment and Test #2 Highway Segement

Baseline # 2 Highway Lap Times (Target Time: 1:27:12)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:27:11	1:27:10	0.019%	Truck 01	Truck 02
Run #2	1:27:10	1:27:08		-0.019%	-0.038%
Run #3	1:27:11	1:27:11		0.000%	0.019%

Test # 2 Highway Lap Times (Target Time: 1:27:12)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:27:11	1:27:10	0.000%	0.000%
Run #2	1:27:10	1:27:10	-0.019%	0.000%
Run #3	1:27:11	1:27:10	0.000%	0.000%

Baseline # 2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	65.60	61.90	0.9436	
Run #2	63.95	61.30	0.9586	-1.586%
Run #3	65.15	61.20	0.9394	0.448%

Test # 2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	66.85	62.55	0.9357	
Run #2	65.85	61.45	0.9332	0.267%
Run #3	65.75	61.50	0.9354	0.034%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	1.31%	± 2.58%
Improvement	1.33%	± 2.62%

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Test #2 City TC Ratios and Lap Times
Baseline #2 City Segment and Test #2 City Segement

Baseline # 2 City Lap Times (Target Time: 1:48:30)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:48:30	1:48:31	0.015%	Truck 01	Truck 02
Run #2	1:48:33	1:48:31		0.046%	0.000%
Run #3	1:48:30	1:48:32		0.000%	0.015%

Test # 2 City Lap Times (Target Time: 1:48:30)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:48:33	1:48:32	0.046%	0.015%
Run #2	1:48:32	1:48:32	0.031%	0.015%
Run #3	1:48:30	1:48:32	0.000%	0.015%

Baseline # 2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	73.65	70.40	0.9559	
Run #2	72.80	69.55	0.9554	0.054%
Run #3	71.75	67.75	0.9443	1.216%

Test # 2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	73.00	67.80	0.9288	
Run #2	71.95	67.20	0.9340	-0.561%
Run #3	72.60	68.55	0.9442	-1.663%

Test Results		
	Nominal	Confidence Interval
Fuel Saved	1.70%	± 1.72%
Improvement	1.73%	± 1.75%

Baseline Highway TC Ratios and Lap Times Comparison
Baseline #1 Highway Segment and Baseline #2 Highway Segement

Baseline # 1 Highway Lap Times (Target Time: 1:27:12)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:27:11	1:27:09	0.038%	Truck 01	Truck 02
Run #2	1:27:11	1:27:05		0.000%	-0.076%
Run #3	1:27:10	1:27:09		-0.019%	0.000%

Baseline # 2 Highway Lap Times (Target Time: 1:27:12)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:27:11	1:27:10	0.000%	0.019%
Run #2	1:27:10	1:27:08	-0.019%	-0.019%
Run #3	1:27:11	1:27:11	0.000%	0.038%

Baseline # 1 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	68.40	64.30	0.9401	
Run #2	67.50	63.35	0.9385	0.164%
Run #3	66.80	62.90	0.9416	-0.166%

Baseline# 2 Highway Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	65.60	61.90	0.9436	
Run #2	63.95	61.30	0.9586	-1.586%
Run #3	65.15	61.20	0.9394	0.448%

Change in Highway Baseline		
	Nominal	Confidence Interval
Fuel Saved	-0.76%	± 2.58%
Improvement	-0.75%	± 2.56%

Baseline City TC Ratios and Lap Times Comparison
Baseline #1 City Segment and Baseline #2 City Segement

Baseline # 1 City Lap Times (Target Time: 1:48:30)					
	Lap Time		Time Diffference		
	Truck 01	Truck 02	Initial <0.5%	Repeat ± 0.25%	
Run #1	1:48:36	1:48:32	0.061%	Truck 01	Truck 02
Run #2	1:48:30	1:48:30		-0.092%	-0.031%
Run #3	1:48:31	1:48:31		-0.077%	-0.015%

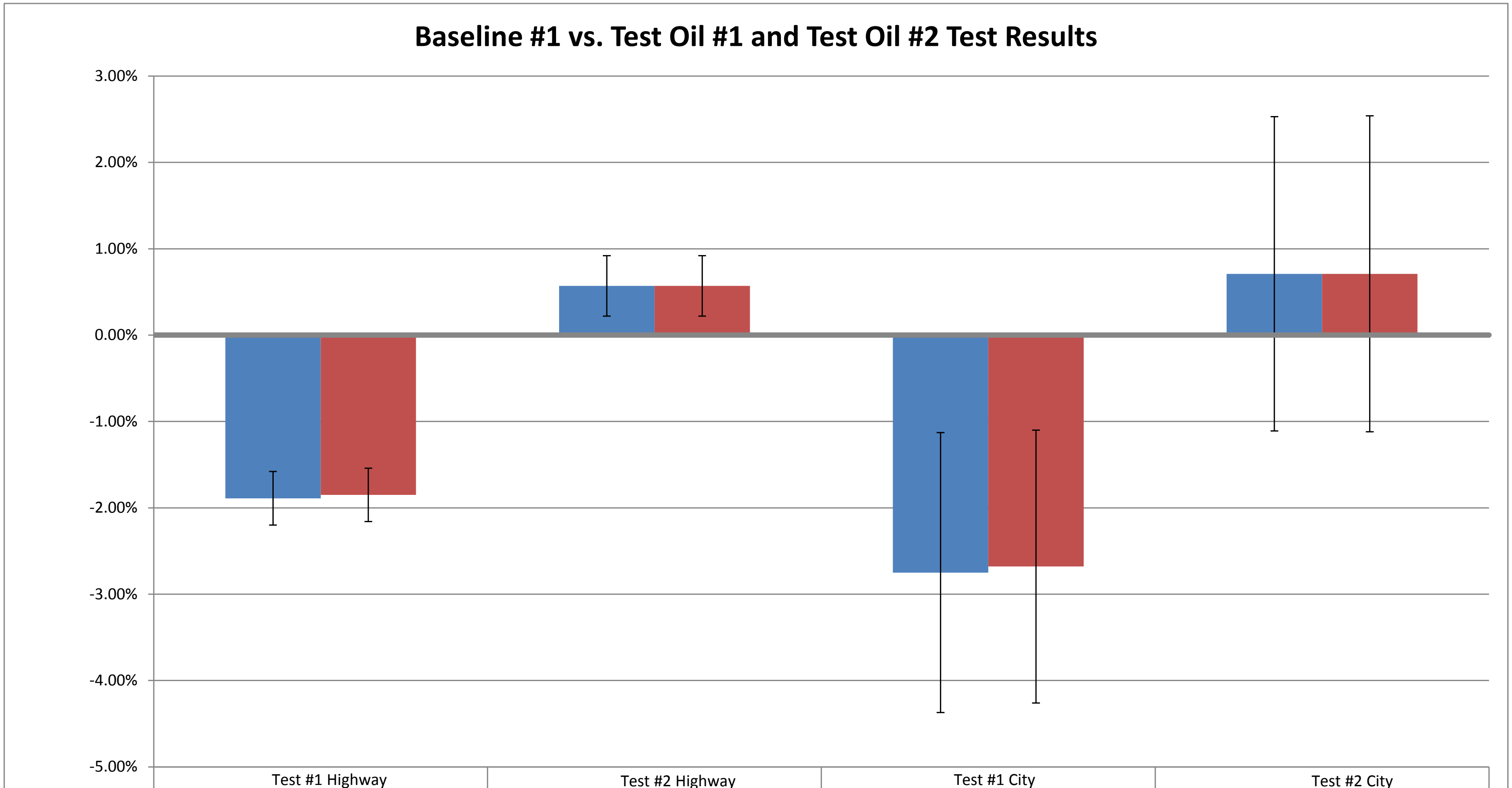
Baseline # 2 City Lap Times (Target Time: 1:48:30)				
	Lap Time		Repeat ± 0.25%	
	Truck 01	Truck 02	Truck 01	Truck 02
Run #1	1:48:30	1:48:31	-0.092%	-0.015%
Run #2	1:48:33	1:48:31	-0.046%	-0.015%
Run #3	1:48:30	1:48:32	-0.092%	0.000%

Baseline # 1 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	74.05	70.30	0.9494	
Run #2	73.35	69.15	0.9427	0.697%
Run #3	72.95	68.20	0.9349	1.524%

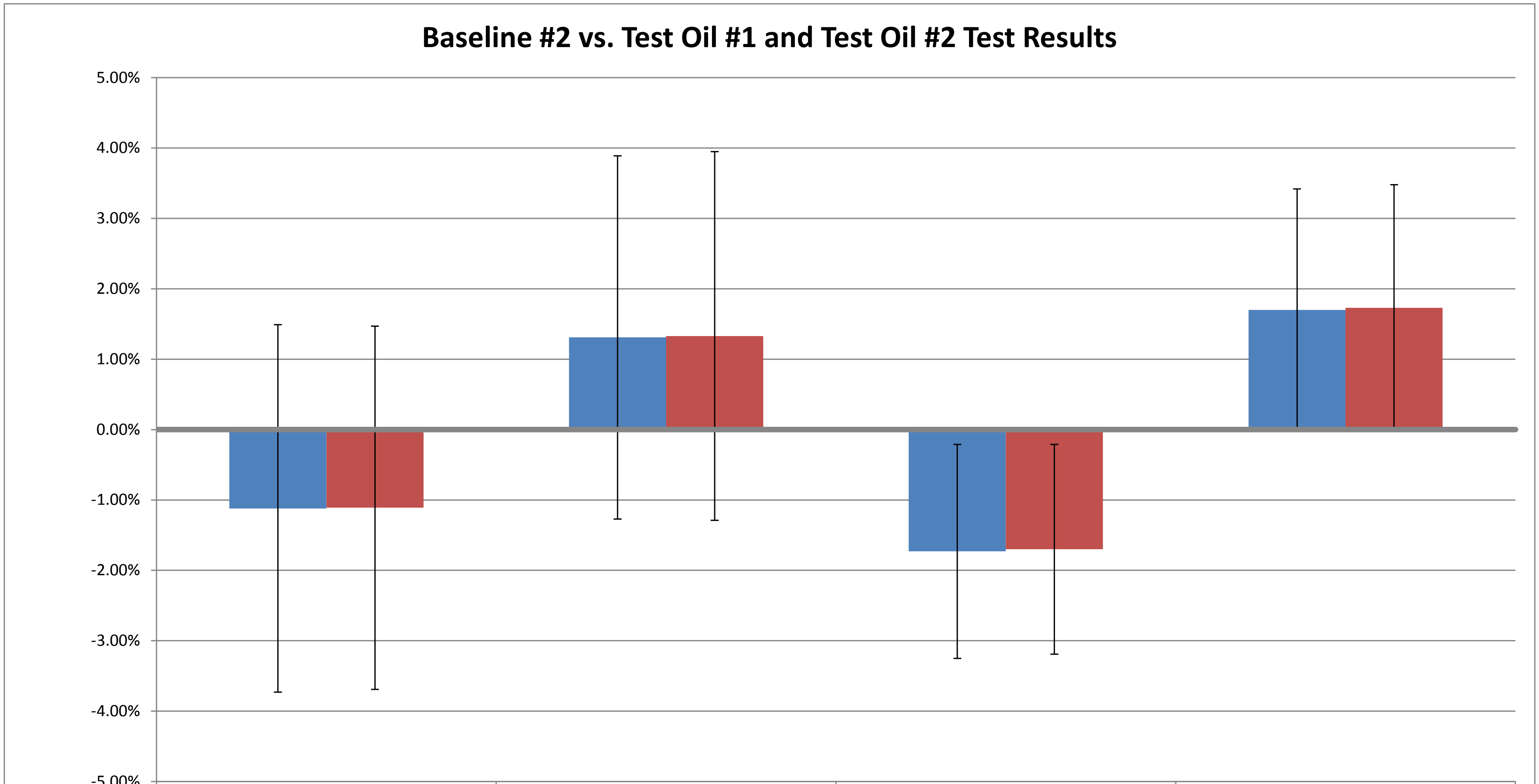
Baseline # 2 City Fuel Weights				
	Fuel Consumed (lbs)			
	Truck 01	Truck 02	T/C Ratio	Difference
Run #1	73.65	70.40	0.9559	
Run #2	72.80	69.55	0.9554	0.054%
Run #3	71.75	67.75	0.9443	1.216%

Change in City Baseline		
	Nominal	Confidence Interval
Fuel Saved	-1.01%	± 1.66%
Improvement	-1.00%	± 1.65%

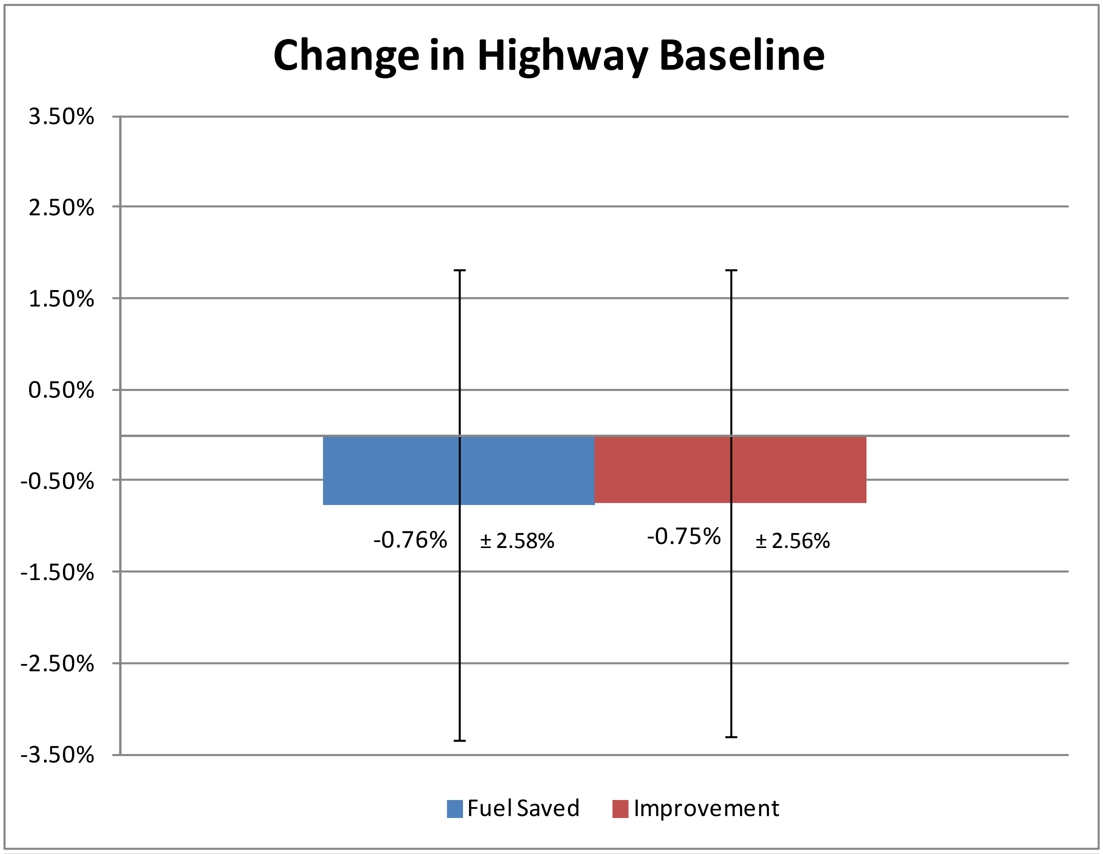
Appendix C
Test Result Graph

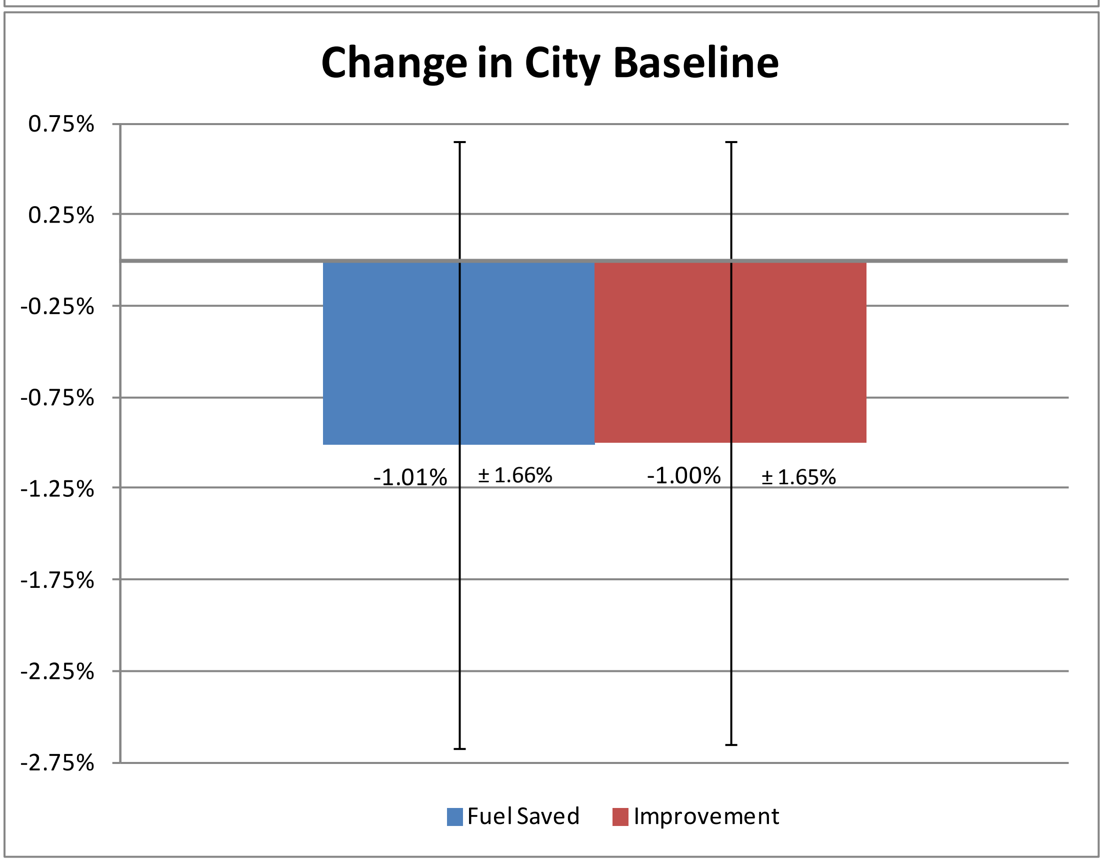


	Test #1 Highway	Test #2 Highway	Test #1 City	Test #2 City
Fuel Saved	-1.89% ± 0.31%	0.57% ± 0.35%	-2.75% ± 1.62%	0.71% ± 1.82%
Improvement	-1.85% ± 0.31%	0.57% ± 0.35%	-2.68% ± 1.58%	0.71% ±1.83%



	Test #1 Highway	Test #2 Highway	Test #1 City	Test #2 City
Fuel Saved	-1.12% ± 2.61%	1.31% ± 2.58%	-1.73% ± 1.52%	1.70% ± 1.72%
Improvement	-1.11% ± 2.581%	1.33% ± 2.62%	-1.70% ± 1.49%	1.73% ±1.75%


Change in Highway Baseline
3.50%
2.50%
1.50%
0.50%
-0.50%
-1.50%
-2.50%
-3.50%
-0.76%
± 2.58%
-0.75%
± 2.56%
Fuel Saved
Improvement

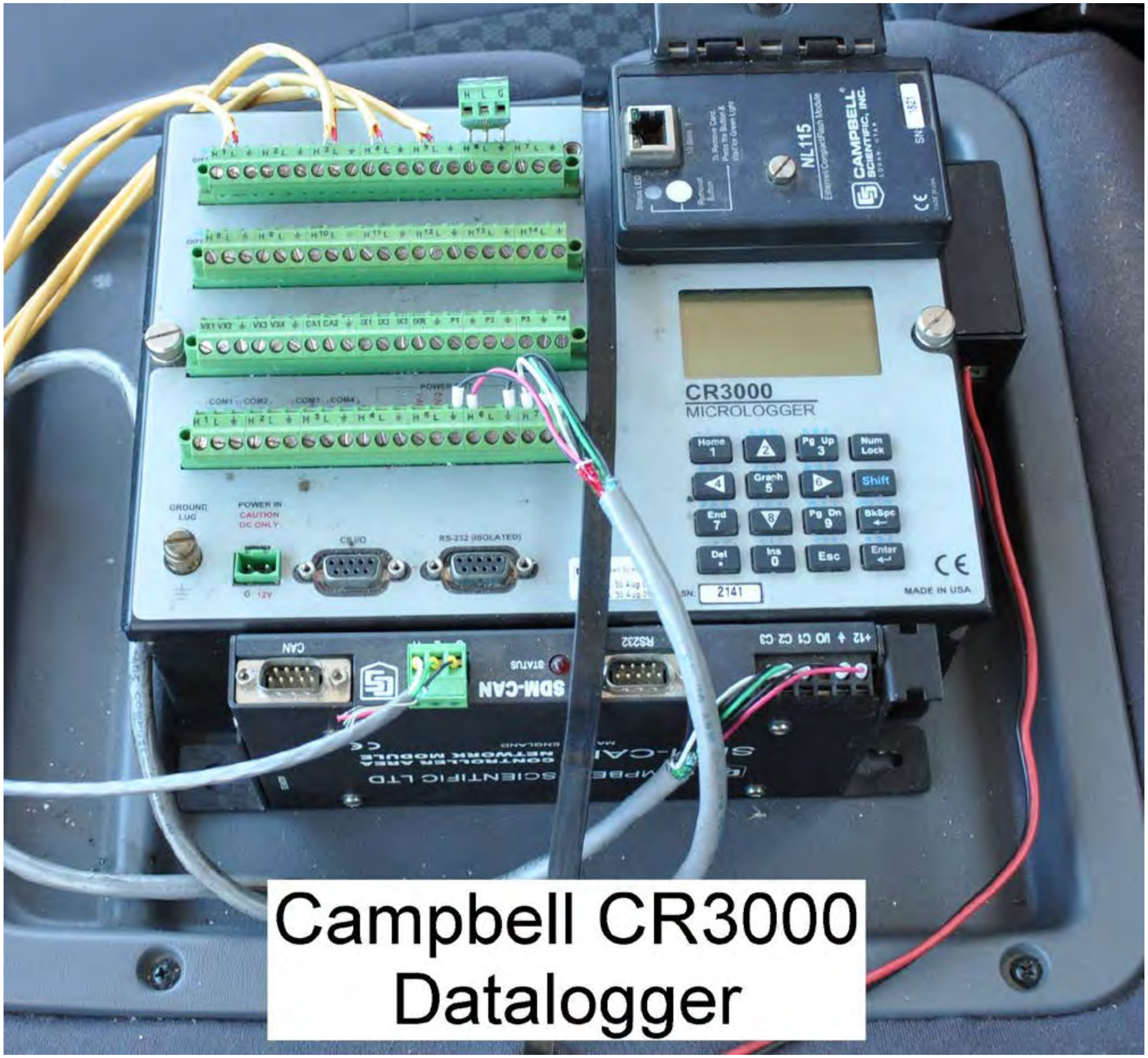

Change in City Baseline
0.75%
0.25%
-0.25%
-0.75%
-1.25%
-1.75%
-2.25%
-2.75%
-1.01%
± 1.66%
-1.00%
± 1.65%
Fuel Saved
Improvement

Appendix D
Photos

Oshkosh M1070 (HET) Test Trucks

Weigh Tank Used For Fuel Consumption Measurements

Three-Way Valve and Fuel Cooler to



Campbell CR3000
Datalogger

Weigh Tank Scale